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Using and Managing Soils

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Using and Managing Soils

By A. F. Gustafson, Ph.D.

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USING AND MANAGING SOILS

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Preface

THE PURPOSE of this book is to provide present and prospective farmers with basic information and practical suggestions on using and managing soils. It is designed for farmers, those who work small acreages, home gardeners, and students of vocational agriculture. The fundamentals of soil conservation and improvement principles are set forth in such a manner as to make clear to the reader the reasons for the practices discussed in connection with the activities included.

Holding the soil in place against washing and blowing and keeping the soil productive over the years are stressed throughout the volume. The necessity for the return of organic matter, fertilization, crop rotations, the proper handling of sour and alkali soils, and drainage, as well as appropriate tillage at the right time under the right conditions, also receive their full share of attention.

Continued neglect and mismanagement of soils leads to lowered crop yields and eventual abandonment. Taking any but poor soils out of production is serious in view of the present rate of population increase and world needs for food, fiber, and oil products. A well-planned, well-understood, and well-carried-out program of soil management on every farm means soil that will continue to produce satisfactorily in accordance with its capabilities.

The author is indebted to Dr. E. V. Staker of Nebraska, H. A. Hopper of the Soil Conservation Service in California, and J. D. Aughtry, Jr., of Texas who read the entire manuscript. Appreciation is also expressed to Dr. T. H. Goodding of Nebraska and Drs. R. E. Blaser and H. B. Hartwig of Cornell University for reading the chapter on Managing Pasture Soils; to Dr. F. L. Duley of Nebraska for reading the chapter on Soil Erosion; to Dr. M. B. Russell of Cornell University who read the chapter on Controlling Soil Water; and to Dr. H. O. Buckman, also of Cornell University, for his assistance on the appendix. Many helpful suggestions offered by these men were incorporated in the final draft of the manuscript. Acknowledgment of the source of each illustration that is not the work of the author appears in the legends used. To all others who assisted in any way, the author expresses sincere appreciation and gratitude.

A. F. GUSTAFSON

Contents

Editor's Foreword

TO a good many people, soil merely means the ground on which we move about and make homes, or the dirt from which plant growth and crop products somehow emerge. Most of us fail to appreciate fully how much we depend on the soil and how essential it is to the survival of the human race.

A fertile soil is one that produces satisfactory plant growth and crop yields and continues to do so. The responsibility of farmers and ranchers, as well as other soil users, is to work and manage it intelligently for both present and future needs. The soil is man's trust and, like a bank account, something must be "deposited" if the "withdrawals" made by crops grown are to be continued.

Soil conservation, which has been receiving nationwide attention and much concerted action in the past twenty years, involves holding soils in place, maintaining fertility, and putting the land to the best use in accordance with its capabilities. The matter of appropriate land use is illustrated in the story of an old Indian who, years ago, was watching the white man's plow rip up certain plains grasslands. It is said that he solemnly held out his hands, palms up, and then quickly turned the palms down. This was his interpretation of "wrong side up." In more than one instance during the past two decades, this Indian's point of view has proved sound.

In this book, the important activities which are a part of working and handling the soil properly are presented in a practical and interesting manner. This book is unique in its organization, arrangement, and approach. Based on reliable scientific experimental work and actual soil experience, the information included is designed for both present and prospective farmers.

The author, Dr. A. F. Gustafson, is a well-known and recognized authority in his field. As a close student of the relation of soils to agriculture, he has spent years in research work, and in teaching and writing about his chosen subject. Those who are truly interested in profitably using and satisfactorily managing the soil will find this book a source of help and inspiration.

W. A. Ross

FRONTISPIECE. Using and Managing Soils Properly Is Every Citizen's Responsibility
The Oliver Corporation).

1. Getting Acquainted with the Soil

THE soil is of the utmost importance in the production of man's food. Fruits, grains, and vegetables depend largely upon the soil for their growth. Meat, milk, and eggs for food, as well as wool, silk, and furs for clothing are produced indirectly from cereals, forage, and other plants. Both cultivated crops and wild plants grow in the soil. In addition, the waters of ponds, streams, lakes, and the sea supply large quantities of important food. Although fish, crustaceans, and other marine life develop in water, they also depend indirectly upon the soil for a part of their sustenance. Likewise, raw materials for clothing, shelter, and fuel are grown on the land.

Because of man's dependence on the soil for his very existence, there is need for conservation of the soil and maintenance of its productivity.

Those who hold legal title to land today have, in fact, only a lifetime lease on it. In a sense, they are only tenants. Because future generations are wholly dependent on this same soil, the land in reality belongs to the people. The landowner possesses the soil and uses it for the benefit of his family; in addition he markets any surplus products for use by other people. The land must not be allowed to wash away or to lose its power to feed the population. In the broadest sense the land is the first interest of all the people because it is the source of so many necessities of life. Future generations, not alone the present landowner and the present generation, have a vital stake in the *conservation and preservation of the soil through proper use and management.*

The constant aim and purpose of every owner and operator of land should be to keep its inherent productivity high. The efficient, thinking farmer can cultivate the soil so as to maintain it unimpaired or increase its virgin productivity. He may even improve the soil with profit to himself and his family. Future generations have every

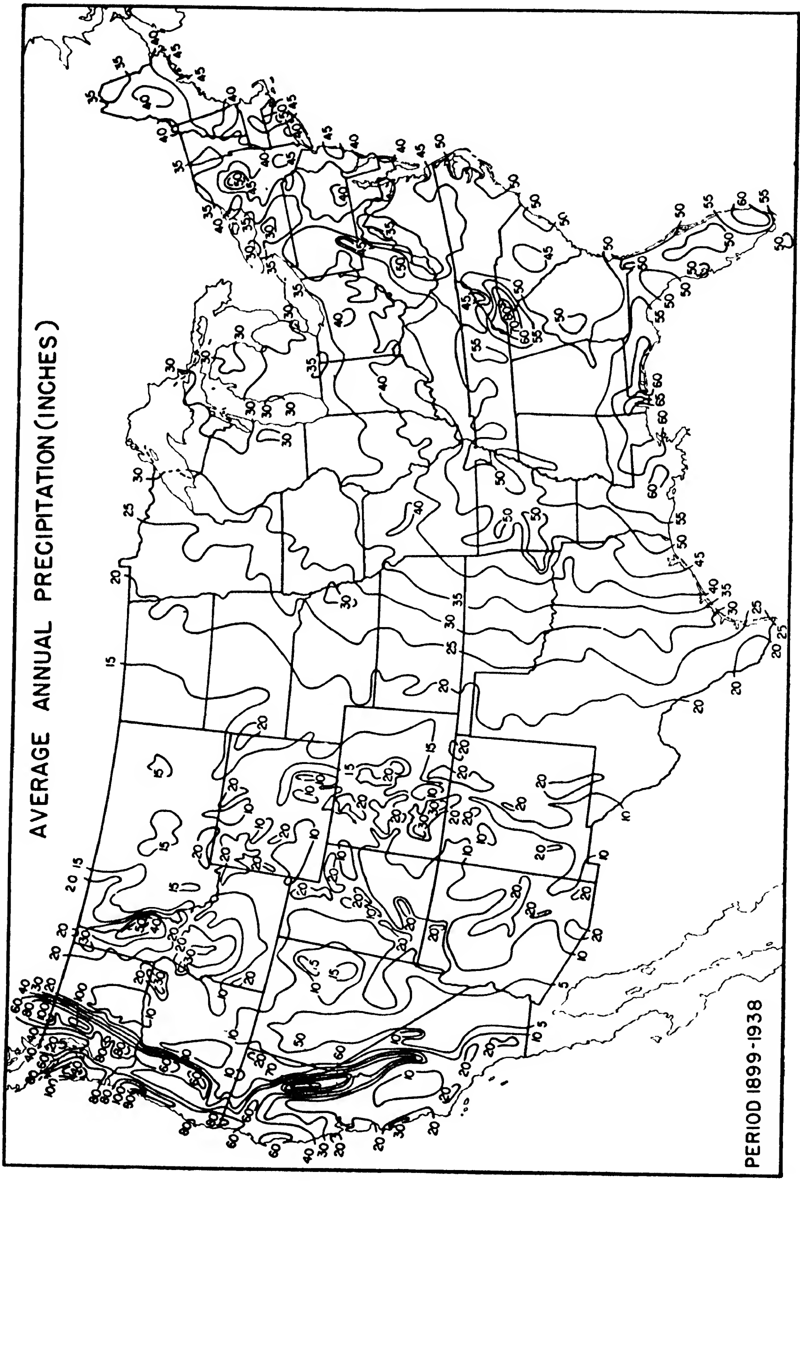

FIG. 1. Precipitation in the United States. The lines show the areas that received different amounts of water, by variations of 5 inches, for the period 1899 to 1938. (*U.S. Weather Bureau.*)

right to expect abundant, health-giving products of well-maintained soils exactly the same as people do today.

Crops require light, heat, air, and water for their growth, along with a foothold in the soil and plant nutrients from it. Light and air are usually present in abundance, and over them man has but little control. Heat comes from the sun and may be controlled to some extent by the farmer. The amount of water that falls on the earth in a given locality cannot be influenced by farmers. They may, however, remove excess water by drainage; they may store water in the soil for crop use during dry periods; and they may apply water to, or irrigate, the soil in the drier areas. Moreover, farmers may so manage the soil as to help crops to obtain the water and nutrients they need. In addition, proper tillage, planting, and cultivation help crops to obtain the necessary foothold in the soil and help control weeds, with which most crops cannot compete successfully.

On the pages that follow will be found information on the formation, make-up, and properties of soils and on their successful management. This information will assist in the production of crops today and may help both present and prospective farmers in the long-term management, fertilization, and conservation of the soil. Getting acquainted with the soil is discussed under the following headings:

1. Becoming Familiar with Soil Formation and Make-up
2. Classifying Soils As to Origin
3. Classifying Soils According to Size of Soil Particles
4. Determining the Properties of Soils
5. Comparing Soil Temperatures and Conditions Affecting Soil Temperatures
6. Making Use of Soil Studies and Other Soil Information

1. Becoming Familiar with Soil Formation and Make-up

The land surface of the earth is covered with a layer of soil material varying from a few inches to 100 feet or more in thickness. Over large areas the soil is from 20 to 40 feet thick. A thickness of from 4 to 8 feet is the least that generally serves satisfactorily as a foothold, a place for the development of the roots of crops and for the storage of water. In the drier regions, greater soil depth is needed for adequate storage of water.

Many chemical changes in the soil material result from the action of natural agencies. It is thus that plant foods are made available for

use by plants. Originally, wild plants grew in nature, died, and fell to the surface of the soil. Here they were broken down by low forms of plant life called *soil organisms*. They used the dead plant materials, called *organic matter*, for food and growth. Certain products were left that became food for the higher plants, such as our crops. As this cycle of growth, decay, and liberation of waste products and their use in growth by other plants continued throughout the long ages, the natural supply of organic matter accumulated in the soil. This organic matter and the finer mineral particles hold water from rain and snow in the soil so that plant roots can obtain and use it in growth.

Organic matter in moist soil under the action of soil organisms changes some parts of the insoluble rock fragments to chemical forms that plants can use as a source of food. At least 14 chemical elements are known to be needed by plants for growth. Of these, 10 are supplied directly to plant roots by the soil; they are *phosphorus*,[1] *potassium*, calcium, magnesium, sulphur, iron, boron, manganese, copper, and zinc. Of the other four, *nitrogen* is obtained from the soil by most plants and carbon, oxygen, and hydrogen from air and water. Legumes, however, usually obtain nitrogen from the air.

In Table 1 are given the names, symbols, combining weights, and sources of the elements that are essential for plant growth, along with a few others that are associated with soil acidity, fertilizers, or important soil-forming rocks.

Soils contain these elements in different proportions. A few soils have all of them in abundance; others are well supplied with some of these essential elements but poorly supplied with others.

Although some of the elements are present in abundance in certain soils, they are in a form that is not available to plants. Such a soil, therefore, is not naturally a productive one. Unless the farmer can help to make all of the needed elements available to crops, it will be necessary to add them in usable form as fertilizers and manures. Every crop takes plant food from the soil. To continue to grow crops over the years, therefore, the farmer returns to the soil the unused remains of crops, animal manures, and certain plant-food elements present in fertilizers.

Weathering of Rocks. In the place in the earth where rocks were formed, they were fairly stable. When earth movements and changes in the earth's crust expose rocks on the surface of the earth,

[1] The three elements in italics are often called the fertilizer elements.

however, breakdown by some or all of the weathering agencies begins. This breakdown process continues until the rock is all changed or until the blanket of weathered material protects the fresh rock from further change. Both physical and chemical forces are active in the weathering process.

TABLE 1. CHEMICAL ELEMENTS USED BY CROPS

Element	Symbol	Combining weight	Source
Boron	B	10 82	Soil
Calcium	Ca	40 08	Soil
Carbon	C	12 00	Air (mainly)
Copper	Cu	63 57	Soil
Hydrogen	H	1 008	Water
Iron	Fe	55 84	Soil
Magnesium	Mg	24 32	Soil
Manganese	Mn	54 93	Soil
Nitrogen	N	14 008	Soil and air
Oxygen	O	16 00	Water and air
Phosphorus	P	31 02	Soil
Potassium	K	39 096	Soil
Sulphur	S	32 06	Soil
Zinc	Zn	65 38	Soil
Other Elements*			
Aluminum	Al	26 97	
Chlorine	Cl	35.457	
Cobalt	Co	58 94	
Sodium	Na	22.997	
Silicon	Si	28 06	

* These elements are present in soils. They are associated with soil acidity, fertilizers, or important rocks.

Physical Forces. Physical forces reduce rocks to smaller and smaller fragments that range in size from immense boulders to tiny soil particles. Further reduction in size continues year after year. Alternate heating and cooling, both daily and seasonal, cause expansion and contraction of the outer layer of grains of rocks. Repeated heating and cooling loosens and separates these outer grains. Water enters the openings between them and, upon freezing, forces the grains apart. This permits a thicker film of water to get in between the particles and freeze. As this is repeated they are forced farther and farther apart and eventually are broken loose completely from the rock. These coarse grains are sometimes found at the base of granite boulders. In freezing, water exerts a force of 150 tons to the square

foot. This force and that of heating and cooling are nearly irresistible. Little wonder that the outside of rocks is shattered by these physical forces.

Other physical forces such as glaciers, waves, streams, winds, and ocean- and lake-shore currents move disintegrated materials about. In so doing they are rubbed against each other and, in places, against the bedrock over which they are moved. This rubbing and bumping further wears them down and produces large quantities of fine rock materials.

Animals and plants also share in this work, but theirs is a minor role. Burrowing animals grind and mix soil materials. Plant roots enter cracks in rocks and wedge them apart. Thus, other agencies are given an opportunity to operate. The results produced by these physical forces are called *disintegration*.

Chemical Agencies. Chemical agencies attack the exposed surfaces of rocks at the same time the physical agencies are at work. The chemical changes are collectively termed *decomposition*.

Such soluble compounds as calcium, potassium, sodium, and iron are removed from rock materials by the downward movement of rain water. This loss leaves rock surfaces slightly porous and they absorb water; freezing further disintegrates them.

Some rock materials take up oxygen chemically, or undergo oxidation, and expand in volume. Some oxides, such as those of iron, take up water chemically or become *hydrated*. Both oxidation and hydration cause an increase in bulk. Like freezing, this expansion loosens the outer part of rocks and exposes more surface for attack by chemical agencies. The products of oxidation, hydration, and other chemical action are quite unlike the rocks from which they come. The new materials have undergone chemical change. Disintegration, in contrast, merely reduces the size of rock materials.

The weathering process is one of reducing rocks to finer materials, of leaching out soluble products that have already been altered, and, in turn, building up new products from the old ones.

Rate of Breakdown of Rocks. Some rocks are changed to soil material faster than others, and some weather faster under one set of climatic conditions than in others. Coarse-grained rocks are disintegrated faster by heating and cooling and freezing and thawing than are fine-grained or glassy ones. Coarse-grained sandstones are weathered faster than noncrystalline quartzite, although these rocks

are of similar chemical composition. Dark-colored rocks absorb more heat in bright sunshine than do light-colored ones. The result is more expansion and contraction. Dark-colored rocks, and more especially those that consist of mixed dark- and light-colored minerals, disintegrate more rapidly than do light-colored ones, because of differences in expansion.

Rocks that contain an *element of weakness*, such as calcium, magnesium, sodium, potassium, or iron, are rather easily decomposed. After oxidation or hydration some of the new compounds are leached away. Because of the increase in volume that has occurred and the entrance of water with attendant freezing and thawing in cooler climates and continuous leaching in hot, humid ones, weathering goes on rapidly. In either hot or cold dry areas, nearly all of the weathering is disintegration. These are some of the simpler examples of weathering, which, as a whole, is a rather complex process.

In terms of the years of man, the formation of soil material is a slow process. There is some variation in the estimates of geologists as to the time required. Chamberlin[2] estimated that not more than 1 foot of soil material as an average over the country had formed in 10,000 years. According to his estimate, it took 40,000 years for the formation of the 4 feet of soil material next above bedrock. *Slow, indeed*, then is the process of soil formation!

2. Classifying Soils as to Origin

Much soil material now rests where it was originally formed from rocks. This is termed *in-place* or *sedentary* material. Other material was moved over varying distances from its place of formation, and this is called *transported* material.

In-place Materials. Of the in-place materials there are two types or kinds: the inorganic, or *residual*, materials from rocks and the *cumulose*, or organic deposits. Although the term cumulose has long been in use, the term *organic* deposits will be used in the pages that follow.

Residual Soil Materials. Residual soils occupy an important place in the United States. They cover the area south of the glacial boundary (Fig. 9) and east of the Mississippi River. The Coastal Plain and the wind-laid and stream-laid materials are exceptions.

[2] CHAMBERLIN, T. C., Soil Wastage, *White House Conference of Governors, Proceedings*, Washington, D.C., Sixtieth Congress, 2d Session, *House Document* 1425, pp. 75–83, 1908.

In addition, the southern part of Missouri, northwestern Arkansas, the southeastern part of Oklahoma, and many local areas in the western states have residual soil materials.

In this country, the younger residual soil materials show a relationship to the *parent rock* from which they were formed. Because of the dominating effect of climate (temperature and rainfall) in the weathering of rocks, the older residual materials tend to be similar regardless of the parent rock. This is particularly true of the older soil mate-

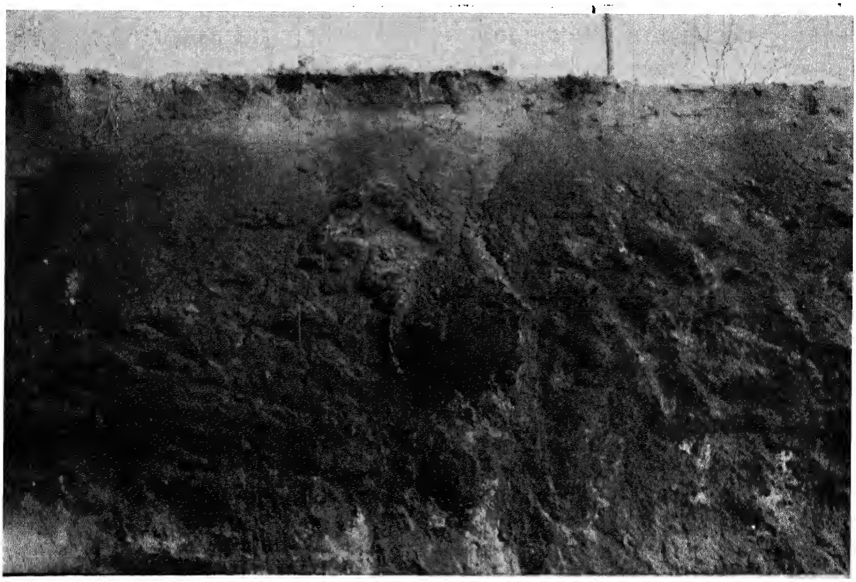

FIG. 2. Residual soil material formed by the weathering of granite near Athens, Georgia. Variations in the color of the upper horizons are visible in the profile. This is Cecil sandy loam. (*W. O. Collins, University of Georgia.*)

rials in the tropics. Residual materials from limestones consist of the impurities contained in the original rock. The materials usually are relatively fine and consist mainly of silt and clay with some coarser particles. The calcium and magnesium of the limestone was dissolved and leached away as bicarbonates. Leaching has been so intense that calcium and magnesium carbonates usually are unimportant, if not entirely lacking, in residual material from limestones. This residual material often is yellow, grayish yellow, or reddish yellow in color.

Residual materials from shales and low-quartz granites in humid

climates usually consist of fine particles. The material from sandstones and high-quartz granites consists of coarse particles. Residual limestone material lies directly on the fresh parent rock. In contrast, granites are strongly weathered on the surface but less and less weathered downward to the fresh unweathered granite. Where little of the weathered material has been washed away, the change from fresh rock below to soil material on the surface may occupy a layer from 50 to 100 feet or more in thickness.

In dry areas, particularly in deserts, disintegration dominates the weathering process. Under these conditions, soluble compounds accumulate in the soil material because there is little water to leach them away. Wholly different material, therefore, may be formed from the same rock in dry climates compared with that in humid ones.

Organic Soil Materials. Organic soil materials were formed in the water of lakes, ponds, or swamps or other wet places. The plants grew, matured, and remained in or fell into the water where they have been preserved. Since this material does not readily decay in water, it accumulates mainly in the place where the plants grew. In addition, leaves and pollen fell into the water or onto wet surfaces and remained wet through the years. Consequently, this material decayed slowly and accumulated there.

These plants ranged in size from microscopic ones to trees. In some places small plants grow for many years and eventually form a floating mat of live and dead material on the surface of the water. In time, shrubs and trees become established there. Trees are blown over, break through the surface, and settle to the bottom along with the other plant materials. Over scores of centuries this process may be repeated many times. Such bodies of water become filled with well-preserved organic matter. Enough decay takes place on the surface for the establishment of a wide range of plants. They pass through the cycle already described and build up deep organic deposits. There are places today where a mat of organic matter covers the surface of the water. Dead plant material settles to the bottom and eventually fills shallow lakes and ponds. Thus, organic deposits are in process of accumulation at the present time.

Many plants grow on soils that are wet much of the year and in places that are kept wet by spring water. Sphagnum moss, reeds, sedges, woody plants, and trees are the principal sources of organic soil materials. Upon decay the moss produces soils of relatively low

productivity, reed and sedge material is intermediate, and woody material from shrubs and trees makes the most productive organic soil in the northern part of the United States (Fig. 3).

Scattered organic deposits are found in the glaciated area from western Minnesota eastward, with the exception of southern Ohio, Indiana, Illinois, and Iowa, and northern Missouri. They are found

FIG. 3. Organic soil in western New York. This fine crop of lettuce is growing on the muck of the Oak Orchard swamp in that state.

FIG. 4. Peat in the Everglades. Lunch time in the bean-picking season. These valuable lands are devoted largely to vegetable production. (*R. V. Allison, Florida Agricultural Experiment Station.*)

also along the Atlantic Ocean and the Gulf of Mexico, and in the Mississippi and tributary bottom lands (Fig. 4). In the West, organic deposits are found in western Washington and California and in south-central Oregon. There are 25 million acres[3] of organic deposits in the United States; nearly 11 per cent of this acreage is in agriculture, including pasture.

Transported Soil Materials. Soil materials have been moved from the place where they were formed by such forces or agencies as gravity, streams, winds, and glaciers.

Colluvial or Gravity-placed Materials. Colluvial, or gravity-placed, soil materials were moved by gravity from the place of their formation to their present location. It may be pointed out, however, that gravity played a minor part in the placing of all transported soil materials. As cliffs weather, the pieces of rock fall to their base. As these accumulate, other chunks roll outward from the base of the rock. As this process continues, a steep slope forms that corresponds to the *angle of rest.* Such material is usually coarse, and rather steeply sloping and seldom forms productive soil. The probable location of colluvial soil materials will be mainly in the mountainous areas as shown on the relief map (Fig. 5).

Alluvial Soil Materials. The materials transported and left by streams are termed *alluvial* deposits. Water that flows over bare soil materials on slopes or in stream beds tends to pick up and carry the finer particles and to roll or shove the larger ones along. A stream current of a given speed or velocity can carry particles up to a given weight, and no heavier ones. A rapid current deposits stones, pebbles, or sand when it is no longer able to transport them. A current of *a* certain velocity transports particles of *a* certain range in size and smaller ones. The smaller particles stay in suspension when the current becomes too slow to move the larger ones farther. Changes in velocity bring about changes in size of material deposited. Thus, layers of coarse material are left by swift currents and layers of finer particles by slower currents. Such alluvial deposits are said to be *stratified.* Alluvial deposits are found in open valleys but not in gorges. The central valleys in California and the Wilamette Valley are occupied by old alluvial soils. When irrigated, these are among the most productive soils in the United States. Of the well-drained

[3] GUSTAFSON, A. F., "Soils and Soil Management," p. 395, McGraw-Hill Book Company, Inc., New York, 1941.

Fig. 5. Relief map of the United States. The large comparatively smooth areas indicate the location of suitable agricultural land. The higher mountainous regions are prominent. (*U.S. Geological Survey.*)

alluvial materials, generally all but the coarsest develop into productive soils.

Marine Soil Materials. Marine soil materials were deposited by streams in arms of the ocean. They are similar to alluvial materials, although nearly lacking in stratification. Some difference between marine and alluvial materials undoubtedly was brought about by the action of the salty ocean water on the marine material. Ages after most of this material was deposited in the salt water, the coast

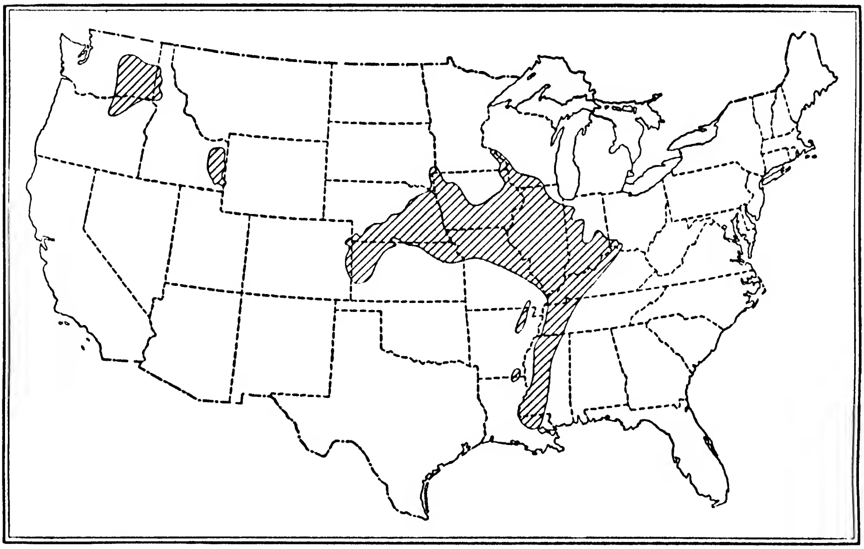

FIG. 6. Principal loess areas in the United States and location of the loess areas with respect to the Missouri and Mississippi Rivers. Highly productive soils were formed from loessial materials. (*Drawn from wide-spread data.*)

line was elevated. This change brought the marine deposits above high tide and they became dry land. Although they are heavy in this country, marine materials, if well drained, form fairly productive soils.

These heavy materials are not to be confused with the coarse, sandy, Coastal Plain material that results mainly from wave action near the surface of the water. There the finer materials are carried away by currents along the shore, leaving the sands behind.

Wind-blown Soil Materials. In total over the centuries, enormous quantities of soil materials have been moved and deposited by winds. Streams are most effective only at flood stage, but the wind acts much

of the time. Sands, silt, and clay (see page 19) are acted on by winds. Sand dunes are the most generally noted and most widely distributed over the country. Winds move sand grains mainly by rolling them along on the surface. High winds do pick up the grains and carry them short distances by a jumpy or jerky movement called *saltation.* At storm velocity, winds carry sand particles through the

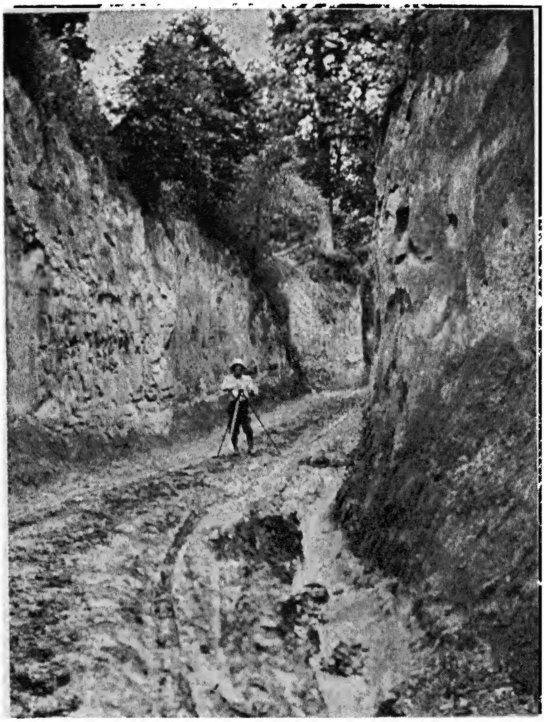

FIG. 7. An exposure of a cross section of moderately deep loess in Illinois. Note the perpendicular walls.

air, sometimes even during the rains. The normal sand dune, however, is built up mainly by the rolling of the particles over the surface.

The important agricultural soil material of wind-borne origin consists mainly of silt particles, although very fine sand and some clay also are present. This wind-borne material is called *loess* or an *aeolian* or *aeolial* deposit. In the United States this material is found in association with the Mississippi and Missouri Rivers and their larger tributaries (Figs. 6 and 7), yet some of the loess came from the Great Plains. Velocity of wind, like velocity of streams, affects the

size of particles carried. Variation in wind velocity is indicated by minor variations in size of wind-borne particles. It is true, however, that the aeolian material in this country is remarkably uniform in particle size. The proportion of very fine and coarse particles is small. Most of it is of the silt size. Loess is easily worked, responds

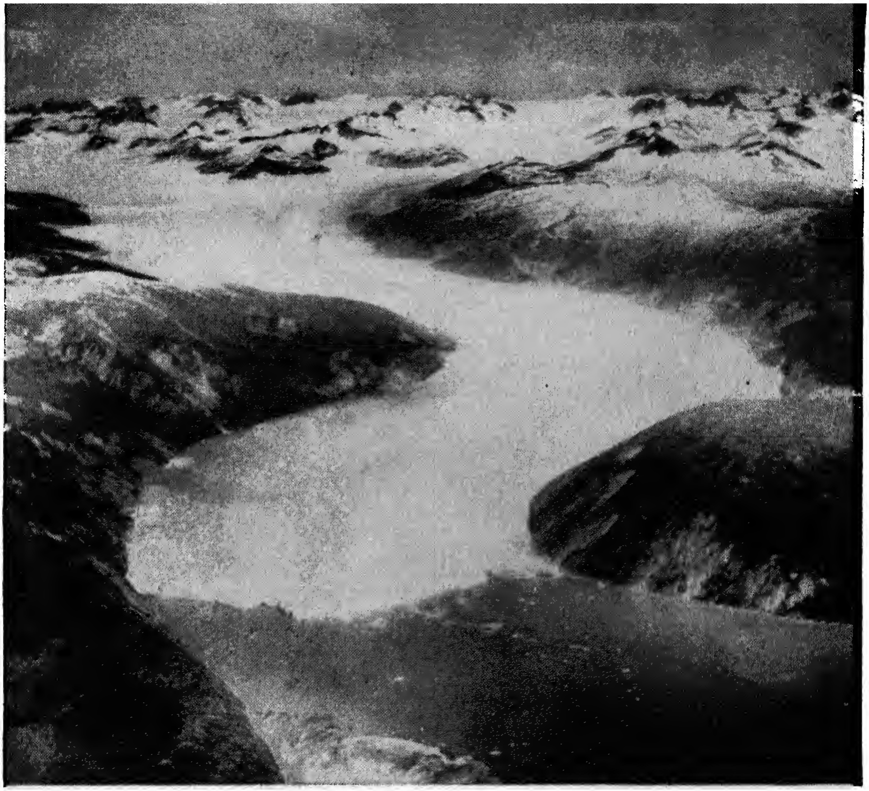

FIG. 8. Taku Glacier in Alaska. The outlet from the snow field takes the form of a valley glacier. Similar tongues of ice extended from the front of the ice in narrow valleys in the hilly and mountainous parts of this country during glacial time. (*U.S. Forest Service.*)

well to tillage and treatment, and in general forms highly regarded, productive soils.

Glacial Materials. Thousands of years ago immense ice sheets came from the north and covered Canada and the northern part of what is now the United States. Such ice sheets are called *glaciers.* These continental ice sheets probably resembled the Greenland and Antarc-

tic ice sheets of today (Fig. 8). Small glaciers, or glacierettes, are found even now in the Rocky Mountains and in many of the high mountains of the world and in the lower ones of the colder areas.

After snow accumulated to great depth in the north, a general outward movement in response to gravity began. The major movement was to the southward, although locally the ice moved in other directions also. The evidence is that the North American glaciers attained really great depth. Even 1,000 feet of glacial ice and

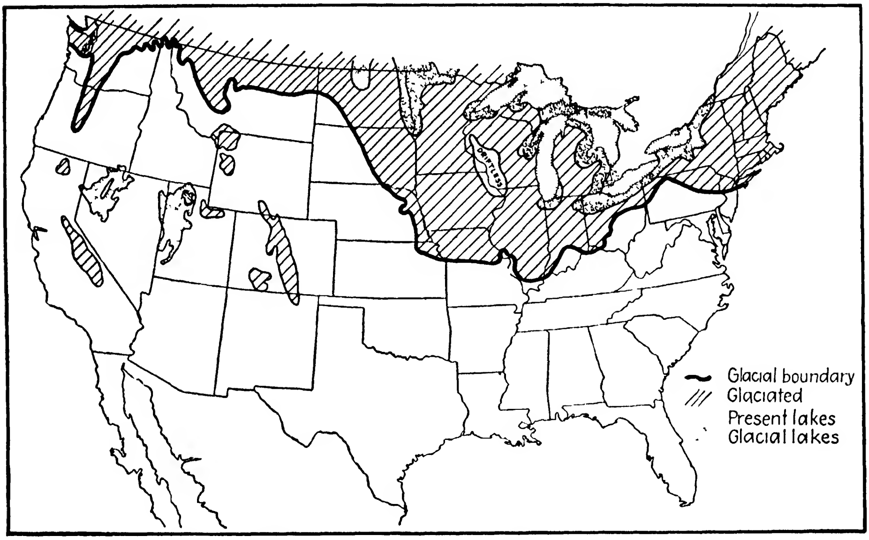

FIG. 9. Region covered by glaciers in the United States. The cross-hatched areas were covered by ice sheets at different times.

included debris exerts a pressure of 50 or 60 thousand pounds to the square foot, and depths of several thousand feet appear certain. Such weight gave the ice great grinding and eroding power. In its movement the ice picked up previously formed soil material, gravel, and boulders and mixed them with the ice.

There were several glacial advances in this country. Each moved forward until thawing at the front equaled, and later exceeded, the forward movement. The glacier then receded and finally disappeared except for remnants in Alaska and the mountains to the southward. The Greenland glacier is probably a remnant of the great continental ice sheet that covered northern North America thousands of years ago (Fig. 9).

During the thawing of the ice the load of weathered soil material and fresh rocks it had picked up in its forward movement was deposited. The depth of these deposits varies greatly, particularly where there are hills and valleys in the rock surface. The glacial material, called *till*, *boulder clay*, or *glacial debris*, is a mixture of fine and coarse material with boulders (Fig. 10). The thawing of the ice released immense quantities of water. Some of it flowed on the ice, some in cracks, and some under the front of the ice. All of this water carried

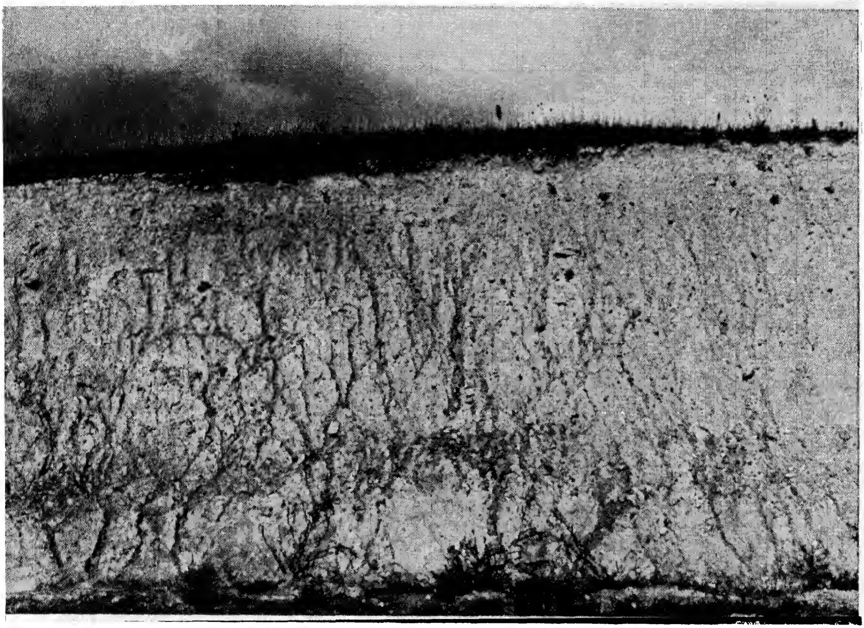

FIG. 10. A glacial deposit—till or boulder clay. In contrast to the uniformly fine material in the deep loess (Fig. 7), note the presence of pebbles and boulders embedded in the finer materials.

soil material—silt, sand, gravel, and boulders—the size of the material depending upon the velocity of the water. These streams assorted or separated the material and deposited it as hummocks or as outwash plains (Figs. 11 and 12). The gravel is stratified in both formations; the layers are nearly level in the outwash plains but sloping in different directions in the hummock material. The hummocks give rise to well-drained to droughty soils; the outwash plains to well-drained and sometimes droughty soils. Many of the glacial-till formations developed into productive soils, particularly if limestone and other fresh rock were prominent in their make-up.

Fig. 11. Cross section of a glacial outwash plain. Water from the front of the thawing glacier carried immense quantities of stones, gravel, sand, silt, and clay. The current was so rapid that the clay, silt, and much of the finer sand was carried far beyond the location of the gravel deposits. The layering, or stratification, is brought about by variations in the swiftness of the outwash streams. Such gravels are valuable as road and building materials. Productive, but sometimes over-drained soils develop on these outwash plains.

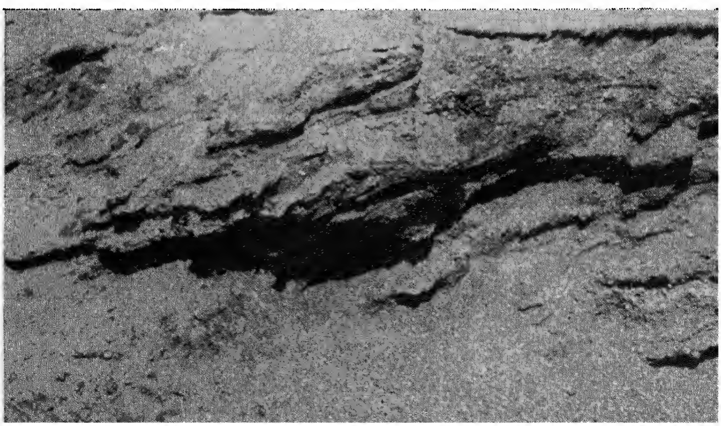

Fig. 12. Gravel deposit cemented with calcium carbonate. The cementing material was dissolved from the overlying limestone gravel and redeposited in its present position. Gravels that contain much limestone often develop into more productive soils than do gravels that consist mainly of noncalcareous materials.

The loess deposits in this country, already mentioned, are associated with the disappearance of the later ice sheets.

Glacial-lake deposits also deserve mention. Where the ice blocked northward-sloping valleys or occupied northward-sloping areas, lakes formed in front of the ice. Streams entering such lakes deposited their coarse material as *deltas* near the shore. The finer material was carried out into the lake and was finally deposited there. This constitutes rather heavy soil material, but because of its good drainage it developed into productive soil.

Soil Formation. The weathering agencies, including glaciers, produced enormous quantities of *soil material.* After ages of further weathering, *soil* may be said to have been developed from the soil material. Low forms of plants appeared and soon were followed by higher forms of plant and animal life. As plants died they decayed and became mixed with the soil. These additions of organic matter changed the soil and made more food available to plants. The soil, then, is a medium capable of supporting higher plant life. The production of soil material and its development into soil are slow and, it should be understood, ever-continuing processes.

3. Classifying Soils According to Size of Soil Particles

Soils consist of mixtures of different-sized mineral particles and organic matter. The separation of a soil into the different size classes is called *mechanical analysis.* The sizes of soil particles generally used in this country are those adopted by the U.S. Department of Agriculture. These particle sizes are given in Table 2.

TABLE 2. SIZE LIMITS OF SOIL PARTICLES*

Names of Soil Particles	Diameter, Millimeters†
Fine gravel	2.0–1.0
Coarse sand	1.0–0.5
Medium sand	0.5–0.25
Fine sand	0.25–0.10
Very fine sand	0.10–0.05
Silt	0.05–0.002
Clay	Less than 0.002

* OLMSTEAD, L. B., L. T. ALEXANDER, and H. E. MIDDLETON, *U.S. Department of Agriculture Technical Bulletin* 170, 1930.

† The upper limit in size of coarse sand is 1 millimeter or approximately 1/25 inch, that of very fine sand, 0.1 millimeter or 1/250 inch, and that of the largest clay particles 0.002 millimeter or 1/25000 inch. From these figures an idea can be gained of the sizes of the different soil particles.

Gravel and sand particles are readily seen with the naked eye; silt and clay particles are not. The coarser particles have a gritty

feel whether wet or dry. Silt has a floury feel. Moist clay is sticky and plastic; dry clay is hard and harsh and difficult to pulverize with the bare fingers.

Soil Classes. Soils that consist of a certain range in size of particles are grouped into classes. The following classes are used:

Gravel Gravelly loam Sand Sandy loam	Coarse-textured soils are dry and early, but usually droughty
Loam Silt loam	Medium-textured, highly desirable soils
Clayey silt loam Silty clay loam Clay loam Clay	Fine-textured soils, retain moisture. often cold and late in spring

Class names indicate the make-up of soils. Sand is composed primarily of the different-sized sand particles; silt loam, mainly of silt; and clay is dominated by fine particles. A loam contains all sizes of soil particles, but none of them gives the soil its own characteristics. Sandy loams have enough sand to give them some of the physical characteristics of sands. Likewise clay loams contain enough clay to have the characteristics of clays.

Sandy and gravelly soils are referred to as *coarse-textured* ones and clayey soils as *fine-textured* ones. Loams and silt loams that consist largely of medium-sized particles are called *medium-textured* soils. Thus used, the term "texture" describes the make-up of soils with respect to the size of their particles.

Soil Types. A soil type is a particular soil in a soil class. In this country, soil types are named from the city or village near which, or the county in which, they are first mapped and described. Thus Sassafras loam along the Atlantic seaboard in the eastern part of Virginia, Maryland, Delaware, New Jersey, and extreme southeastern Pennsylvania differs distinctly in one or more important particulars—such as mode of formation; climatic relationships, including rainfall and temperature; drainage; productivity; or make-up—from Barnes loam in Minnesota and North and South Dakota or the Miles and Vernon loams in northwestern Texas, western Oklahoma, and southern Kansas. Sassafras loam, therefore, is a distinct soil type because it is different in important ways from all other loams. Likewise, for various reasons, any silt loam or any clay in one section of the

United States is a different soil type from any silt loam or any clay in another part of this country.

A single county as mapped by the soil survey of the U.S. Department of Agriculture has from a score or so to 100 or more different soil types. The country as a whole, therefore, has literally thousands of distinct soil types. Many of these types require specific individual management and treatment to produce crops. On the other hand, there are groups of types that respond to the same treatment and management.

4. Determining the Properties of Soils

Soils have many properties; some of the more outstanding properties are discussed here.

Significance of Color of Soils. Three things give soils the color you observe in the field. These are (1) organic matter, (2) the more or less weathered, mineral soil materials, and (3) the quantity and condition of iron present. A fairly high proportion of organic matter, that decayed in soil well supplied with lime, usually gives the soil a brown to black color. Such soils are generally considered productive ones. Under these conditions there is a fairly close relationship between color and the percentage of organic matter in the soil. Under similar conditions, particularly of drainage, the darker-brown-colored soils are more productive than the lighter-colored ones. Black soils, which usually are higher in organic matter than brown ones, often developed in places that have poor drainage over the surface of the soil. When thoroughly drained, however, such soils usually are highly productive.

In soils low in lime, organic matter decayed in such a way that it has little effect on color. Many well-drained timber soils are light brown, gray, or yellowish gray in color. In these soils the color effect of organic matter is of little aid in judging productivity.

If a soil contains numerous pieces of ground-up black shale, it gives the soil a dark color regardless of its percentage of organic matter. Some sands contain large proportions of a black mineral such as the iron ore, magnetite, and, therefore, are dark in color regardless of organic content. Certain soils contain numerous grains of red sandstone that give the soil a reddish color unless it is very high in organic matter.

Iron in moist air combines with oxygen to form iron oxide. This

happens overnight if a well-polished plow or cultivator shovel is left out in dew or rain. We call this iron oxide rust, and the process that of oxidation or rusting. Fresh iron oxide is red and gives soils a reddish color; the depth of color varies with the proportion of iron oxide present. Iron oxide takes up water and combines chemically with it—a process called *hydration*. As hydration proceeds the iron oxide changes from red to yellow. Thus, if finely divided, iron oxides give soil their color. They are responsible for the red and the varying shades of red and yellow color in soils. The effect of organic matter on color is masked by that of iron oxide in well-drained soils. In poorly drained soils, iron has been reduced or partly deoxidized. In that condition, it imparts a bluish or bluish-gray color to the soil. This color is found in swamp subsoils and in certain deep soil deposits that are well charged with lime.

Significance of Color of Subsoils. Well-drained humid soils in the United States are yellow or red, or vary from yellowish red to reddish or brownish yellow. In fact, these colors may be taken as a definite indication of *good drainage* through the soil. Bluish-colored subsoils occur in areas that are permanently wet or that have been in a swampy condition for many years. If the surface soil is brownish gray and a gray layer occurs from 8 or 10 to 16 or 20 inches under the surface, the soil has slow drainage through it. The gray layer is mottled with yellowish or rust-brown blotches or has soft brown pellets or iron concretions in it. Such soils vary from a condition of essentially no drainage or imperviousness, to slightly mottled *gray* subsoil that is no worse than somewhat slowly drained. Some streaks of gray are found in certain well-drained loessial subsoils of the Mid-west, but the truly well-drained subsoils are yellow. So invariable is this that a mottled gray layer of humid subsoils is taken as an almost infallible indication of slow to poor drainage through the soil. These soils are called *impervious* or are said to have *poor internal drainage*. This condition often bears little relation to surface drainage or runoff on sloping lands.

Properties of Sands. The soil particles of sandy soils are large and the spaces between the particles are large. Water passes down through sands very rapidly. Air circulates freely in sands, and they are said to have good *aeration*. In fact, organic matter "burns out," or rots quickly, in sandy soils. They do not hold water, organic matter, or plant foods to good advantage. Sands, therefore, are

droughty and not naturally productive soils. Sands are easily plowed or cultivated; little power is needed. As a result, farmers refer to sands and sandy types as "light" soils even though they are heavy in actual weight.

Properties of Silt. Silt particles are not nearly so large as sand particles. The openings between silt particles are much smaller than between those of sands, yet drainage through silt loams is good enough for most crops. Silt is always associated with other sizes of particles and the mixture is called silt loam. Silt loams hold water, organic matter, and plant food to better advantage than do sands. Crop roots penetrate average silt loams easily, and they are ideal for the growth of many crops. The heavier silt loams, particularly those low in organic matter, do run together or are puddled if plowed or cultivated while too wet. Some care, therefore, is needed to avoid injuring the physical condition of heavy silt loams.

Properties of Clay. As shown in Table 1, clay particles are the smallest of all. They are visible only through the use of high-powered microscopes. Clay acts like jellies and glues; in fact, like them, clay is *colloidal* in nature. The average size of colloidal particles has been calculated to be a little more than 0.0001 millimeter or 1/254,000 inch in diameter. The combined surface area of the colloidal particles in a cubic foot of soil is from 150 to 200 acres. Although this seems incredible, it helps to explain the high water-holding power and the ability of clays to hold gases and plant-food materials. In soils that are in satisfactory moisture condition for crops, these particles are surrounded by a thin film of water. Because of the large area of contact, the water brings comparatively large quantities of plant food into solution for use by crops. In fact, colloidal matter in soils serves as a reservoir for plant-food materials.

Colloidal clay governs the plasticity, tenacity, shrinkage, and puddling of soils. Very wet clay soils have little plasticity and dry ones have none, but moist clays are highly plastic. Moist clay soils are very tenacious; that is, they stick together and are difficult to pull apart. When very wet, however, clays have little tenacity. Because it is difficult for teams or tractors to pull plows and other implements through clay soils or because of the heavy draft, they are said to be "heavy" soils. The terms *heavy* and *light* will be used with these meanings on the pages that follow.

Dry colloidal material takes up much water on being wetted, and

it expands in volume to a marked extent. The opposite is also true; wet clays shrink greatly upon drying. In the field this effect is seen in dry periods in the wide cracks in heavy soils. Clays shrink from 20 to 30 per cent or even more upon drying. This shrinkage breaks off many fine roots of crop plants and reduces crop yields.

Repeated wetting and drying and freezing and thawing of clays that are well supplied with organic matter brings about the formation of little lumps or granules that act more or less like particles of sand. Air can enter a well-granulated soil for the benefit of crops much better than it can a nongranular one.

Driving on wet, heavy soils with teams or tractors, letting livestock run over them, or plowing or cultivating them while they are wet breaks down the granules; such practices *puddle* the soil. In this puddled condition air and water cannot move in the soil freely and crops are injured as a result.

The clay is the most active part of the mineral portion of soils, both chemically and physically. It is also the most difficult to manage in the field. The colloidal material is the most important constituent of soils.

Soil Structure. The term *texture* refers to the size of soil particles; thus there are coarse- and fine-textured soils. *Structure* is used to indicate the condition of soils. Thus a sandy soil, in which the particles are separate or act alone, is one of single-grain structure. In clays, single-grain structure is bad for crops. In heavy soils it is desirable to have a crumb, or granular, structure. Colloidal organic matter as well as colloidal mineral matter is essential for granulation. Soils with suitable granular structure are drained and aerated more quickly, are tilled more easily, and produce larger crop yields than do puddled or poorly granulated ones.

Hardpan and Drainage. A heavy, compact layer under the surface is usually called *hardpan* or *tight clay.* In the presence of this stratum, drainage is very slow, and the soil, as previously stated, is said to be impervious or to have poor internal drainage (Fig.13). This layer may occur from 6 or 8 to 20 inches or more under the surface. In periods of heavy rains on level areas or gentle slopes, water stays in the soil and excludes air. If this condition is prolonged some crops are killed; others are severely injured and yields are greatly reduced.

In some areas the hardpan is at the surface. Probably nature's original topsoil there has been removed by erosion. Few crops make

any worth-while growth on these hardpan spots. These spots are variously known as *scalds*, *scald spots*, or *slick spots*. They are essentially unproductive.

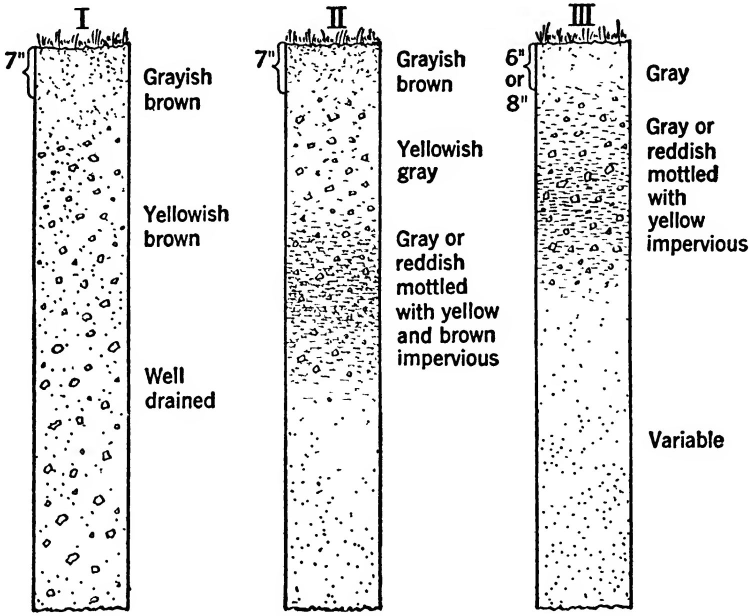

FIG. 13. Soil profiles with different degrees of drainage. There are, of course, variations in depths of surface to the impervious or slow-draining layer. I is well drained; II intermediate, with a slow-draining layer 15 to 18 inches below the surface; III poorly drained, impervious layer 6 or 7 to 10 inches below the surface.

Plow Sole. What is termed the *plow sole* develops in heavy soils that are plowed to the same depth year after year. The weight of moldboard plows on the bottom of the furrow compacts the soil. More compacting occurs if the soil is wet than if it is in the right moisture condition. This plow sole checks drainage and interferes with aeration below the plowed layer. The plow sole can be broken up by plowing only when the soil is dry enough for stirring and by plowing deeper some years than others. Subsoiling for this purpose is practiced in some areas (see page 63).

Specific Gravity. The specific gravity of important soil-forming minerals varies within narrow limits. That of calcite is 2.70; of dolomite, 2.85; of limonite, 3.6 to 4.0; and of old organic matter 1.2 to 1.3. The specific gravity of soils is affected by their mineral make-up and organic content. Silt and clay loams well supplied

with organic matter have specific gravities of 2.57 to 2.62, while timbered silt loams have a specific gravity of 2.65, or that of quartz. This suggests that quartz may be important in the make-up of these soils. Soils of low specific gravity usually have a high organic-matter content.

Volume Weight of Soils. Volume weight, numerically, is the weight in grams of 1 cubic centimeter (see Appendix IV, page 398) of water-free soil. Since soils are not solid but porous, the air or pore space is included in the volume of soil, the 1 cubic centimeter. Including air in the volume explains why volume weight is so much lower than the figure for specific gravity.[4] A compact soil in the spring has relatively high volume weight and little pore space compared with that of a freshly plowed soil. Volume weight is affected, but only slightly, by the specific gravity of the minerals in the soil. Proportion of pore space is the determining element, although organic content has a slight influence. Soils in which the particles are packed closely together are high in volume weight and actual weight per cubic foot or acre foot (1 foot deep over an acre or 43,560 cubic feet).

A silt loam with a good supply of organic matter and in good physical condition has a volume weight of about 1.25 and weighs about 78 pounds to the cubic foot or approximately 2,000,000 pounds or 1,000 tons to the acre 7 inches deep. Compact silt loams weigh from 90 to 100 pounds to the cubic foot. Sands and sandy loams have volume weights of 1.35 to 1.75 and weigh from 84 to 110 pounds to the cubic foot.

Volume weight is of importance in determining the weight of soil from which to calculate the quantity of organic matter or of plant foods in the soil to plow depth. Obviously it is much easier to determine the volume weight of representative samples than to weigh the plow soil over an acre, or even over a fraction of an acre. One thousand tons is generally used as the weight of an acre 7 inches deep; 1,250 tons for sands and sandy loams. Muck soils vary in volume weight with their proportion of mineral matter. They weigh from 500,000 to 1,000,000 pounds an acre 7 inches deep. Volume weight

[4] By specific gravity is meant the relationship between the weight of unit volume of water and that of exactly the same volume of a substance under identical temperature and other conditions. Thus the weight of unit volume of water is 1, that of quartz 2.65. Quartz weighs 2.65 times as much as water which is taken as the standard for comparison. The specific gravity of quartz, then, is 2.65. In the same way, specific gravity is used for soils.

supplies valuable information concerning the tilth of soils; those of low volume weight are in better tilth than those of high volume weight.

Pore Space. A piece of glass is solid and contains nothing but glass. Soil, in contrast, has open spaces between the particles or the granules. In dry soils these spaces are largely occupied by air; in moist soils by air and water; and in saturated soils by water. For the growth of crops a good condition in silt loam soils is the intermediate one in which the soil contains both air and water. Sandy soils contain less pore space than silt loams, and well-granulated, clayey soils often have even more pore space than silt loams. During the growth of crops these proportions are slowly but constantly changing. Figure 14 represents favorable conditions in a good silt loam. As the season progresses, rainfall and gravity compact soils and reduce the proportion of pore space. Heavy rains expel most of the air and its place is taken by water. As the soil drains and dries out, a large share of the pore space is again occupied by the air. A moderate degree of such change is not unfavorable for crops. Soils do become so compact, so lacking in pore space, that crops suffer from a lack of sufficient oxygen.

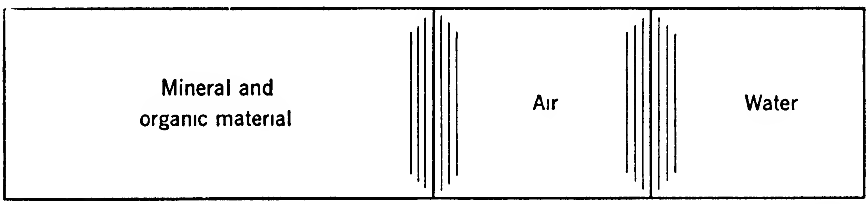

Fig. 14. Relative proportions of solids, air, and water in silt loam soils that are in desirable condition for crop growth. As soils are loosened a larger proportion is occupied by air and water. Later in the season, as soils become compacted, the solids occupy a higher percentage of the space. In dry soils the pore space is mostly occupied by air; in saturated soils water displaces the air.

The size of the pores rather than the percentage of porosity governs the movement of air and water into and out of soils. Sandy and gravelly soils take up heavy rains very quickly because they have large pores. Compact, poorly granulated silt loams and clay loams have small pores, and water passes into or through them slowly. Irregularity in the shape of the pores further checks the movement of water through fine pores. The rapidity of movement of air, or soil aeration, is similarly affected by the size of the individual pores. A large percentage of pore space in moderate-sized pores is most favorable for the growth of crops.

5. Comparing Soil Temperatures and Conditions Affecting Soil Temperatures

The temperature of the soil and of the air above it vitally affects the growth of crops. Certain physical and chemical changes in soils provide some heat, but radiation from the sun provides most of the heat in soils.

Soils lose heat by radiation. This loss is essentially independent of their color. The dark-colored soils take up heat more rapidly in sunshine than do light-colored ones. The dark ones, therefore, are warmer in late afternoons, but by morning they are about the same temperature regardless of color. Air currents and conduction downward into the soil cause losses of soil heat. Drainage of water that has been warmed by the soil takes away heat. The big loss of heat, however, takes place in the evaporation of water from the surface of the soil.

Temperatures Needed for Germination and Plant Growth. There is considerable difference in the temperatures needed for germination and growth by different groups of plants. There are cool-weather crops and hot-weather crops. Some thrive best in cool weather and are injured by hot weather; others thrive only in hot weather. High temperatures may even prevent the germination of cool-weather crops.

Hall, at the Rothamsted Experiment Station, determined the temperatures for the growth of a few crops. His data are given in Table 3.

TABLE 3. TEMPERATURE OF SOIL NEEDED FOR PLANT GROWTH*
(Degrees Fahrenheit)

Plant	Minimum	Optimum	Maximum
Mustard	32	81 0	99 0
Barley	41	83.6	99 8
Wheat	41	83 6	108 5
Maize (corn)	49	93.6	115 0
Kidney bean	49	92 6	115 0
Melon	65	91 4	111 0

* HALL, A D, "The Soil," p 152, E P Dutton & Company, Inc, New York, 1931.

Variation in Soil Temperatures. The farmer has a measure of control over some of the conditions that affect the temperature of the soil but not over others. Slopes receive varying quantities of heat

according to their direction. Slopes facing south and southwest receive the most heat from the sun; those facing north and northeast receive the least. The other directions are intermediate. Soil and air temperatures on hot slopes get too high in midsummer for the growth of certain grasses. These plants grow better on the cooler slopes at that season. Sensitive fruits, nut trees, and such trees as black locust come on too early on the hot slopes. Because of frost injury on these slopes it is better in some areas to plant such trees on the cooler slopes. The farmer cannot control the temperatures on slopes, but he can plant his crops on the slopes that furnish the most favorable conditions for them.

During spring and fall when soils are exposed to the sun's rays, dark-colored spots absorb more heat than light-colored ones. Quicker germination and faster early growth take place on the dark spots than on the light ones with similar slope and moisture conditions. This difference is noted in corn in the spring and wheat in the fall. The seedlings come up 1 to 2 days earlier and grow faster on the dark-colored soils. Moreover, a higher percentage of germination is obtained on the dark- than on the light-colored soils.

The proportion of water in soils affects their temperature in several ways. Approximately five times as much heat is required to raise the temperature of a pound of water 1 degree as is required to effect the same change in the temperature of a pound of soil. The removal of unnecessary water by drainage, therefore, improves the effectiveness of sunshine. It acts to raise the temperature of the soil rather than that of the water. Favorable temperatures for germination and growth will be reached earlier in the spring in well-drained soils than in wet soils.

Another effect of water is related to the quantity of heat required to evaporate it. Much heat is expended in the evaporation of water from wet soils that would be used in raising the temperature of well-drained ones. The higher temperature of the well-drained soil brings about earlier germination and faster early growth. Moreover, the slow germination on the wet soil leads to the rotting of many seeds and a low percentage of total germination. Growth is slower, especially in early spring and late fall, on wet than on well-drained soils.

6. Making Use of Soil Studies and Other Soil Information

Much work has been done on the soils of the United States; far more, in fact, than in most countries, although other countries have

not been idle. Surveys of the soils have been a large part of this work.

Soil Surveys. The soil survey, conducted by the U.S. Department of Agriculture, began mapping soils during the last few years of the last century. Most of the work has been done with the county as the unit both for mapping and for publishing the report. At first and more recently, however, smaller units have been used. Until lately, surveys were made on a scale of 1 inch on the map being equal to 1 mile in the field. In intensive farming areas, some recent soil maps are on a larger scale—2½ to 4 inches to 1 mile. In addition to the Federal Soil Survey, the U.S. Soil Conservation Service is making soil surveys that are being published on a scale of 4 inches to 1 mile. These maps are in five colors; each color indicates the intensity of need for ways of controlling soil erosion and shows the capability of each class of land. The colors are overprinted on the boundaries between soil types. The Federal Soil Survey, in addition, rates soils on the basis of their natural productivity in 10 classes of declining productivity. Class I is the group of soils of top productivity.

Several states have made somewhat similar economic surveys of the land. Some of them definitely show those areas that should be taken out of crop production and immediately planted to trees and those that should remain permanently in crop production. In New York and Pennsylvania the land is classified on the economic basis of the intensity of use. Idle and abandoned land is in Class I. Land that is still occupied and used but which produces a very low return per unit of land is classed as II. Class III, although not highly productive, is rated to remain permanently in agriculture. Classes IV, V, and VI are more and more intensively used. Class IIR is used to indicate areas near cities and villages that should continue to be used for homes because they have good houses on them. The soil, however, is definitely Class II. All of these surveys should be widely used because they represent so much painstaking work and supply so much valuable information. It should be appreciated that these classifications are prepared for different purposes and that they are based on different factors.

SUMMARY

1. The rocks of the earth's crust have been acted upon by weathering agencies and in the weathering processes have been reduced to soil material.

2. Mineral soil materials that remained in the place where they were formed are called residual materials. Organic soil materials also remained in the swamps where the plants grew from which they were formed.

3. Other soil materials were moved from their places of origin by the action of water, winds, or glaciers and were deposited by them in their present location. They are called transported materials.

4. Soil particles vary greatly in size. Among the fine material in soils the largest particles are classified as fine gravel and those of decreasing size as sands, silt, and clay, respectively. Soil classes have been established on the basis of size of particles. A particular soil in a class that differs from all others in that class is designated a soil type.

5. Soils possess many properties of which color is very important. The organic content and the productivity of soils are judged to some extent by the color of the surface soil. In the Middle West are gray timber soils that are low in organic matter and dark-brown prairie soils that are higher in organic matter. Under similar conditions, the prairie soils produce much larger yields than do the light-colored timber soils. The color of subsoils indicates the degree of drainage through them. Yellow and reddish subsoils are well drained; compact subsoils mottled with gray are poorly drained.

6. Sandy soils are open and porous and do not hold water, organic matter, and plant food satisfactorily. Silt and clay loams, in contrast, hold water, organic matter, and plant food to good advantage. Some clays hold too much water and, therefore, are cold, late soils in contrast with sandy soils, which warm up early.

7. Some heavy soils have a well-developed, compact, hardpan layer in the subsoil through which air and water move very slowly. Hardpan soils are poorly drained.

8. Medium- and fine-grained mineral soils weigh about 2,000,000 pounds to the acre 7 inches deep; sands about 2,500,000 pounds. Organic soils to this depth weigh from 400,000 to 1,000,000 pounds an acre.

9. Certain soils, especially coarse-grained or well-granulated ones, have large pores through which air and water pass readily. In them, drainage takes place easily and without much delay after heavy rains. Aeration takes place to advantage in soils that are in this condition.

10. The temperature of the soil varies largely with the temperature of the air, except that water has a marked influence. It takes considerable heat to evaporate water from soils; wet soils, therefore, are cold ones.

11. The many soil studies that have been made include classification and mapping of soils. Some of these studies classify them on the basis of their best use. Soil maps can be of real service to the farmer on the land and to the prospective purchaser of farm land.

2. Selecting Land for Farming and Country Living

SELECTING land for farming and country living is exceedingly important because it determines the labor requirements, the financial returns, and the well-being and happiness of every member of the family. Recognizing that the factors involved are innumerable, the subject will be discussed under the following major activities:

1. Choosing a Type of Farming and an Area for Farming
2. Choosing the Community
3. Selecting Well-drained Farm Land
4. Judging the Productivity of Land
5. Selecting Land Suited to the Type of Agriculture
6. Determining the Suitability of Buildings and Other Improvements
7. Securing Information on Available Water Supplies
8. Checking on Climatic Conditions

1. Choosing a Type of Farming and an Area for Farming

One who does not take over the home farm or select a farm in his local community must first decide on the type of farming to follow. Even when that is done, other decisions lie ahead. In this country, dairying and other livestock farming are carried on over large areas, from New England to Wisconsin and Minnesota and a large area to the southward. The Corn Belt extends from western Ohio to central Nebraska. The Cotton Belt reaches from eastern North Carolina to west-central Texas and south to the Gulf of Mexico. Then there is the range-livestock area of the Great Plains and the Rocky Mountains, as well as scattered fruit, vegetable, and specialty-crop areas. Representative of such crops are cauliflower in the Catskills and grapes and peaches in certain lake areas of New York.

Figure 15 indicates the variation in regions from which to choose an area for the desired type of farming. The cost of land and equipment in general increases with the expected returns from a type of farming. Although fruit or vegetable growers will pay far more per

acre for land, they require fewer acres than do livestock farmers and ranchers. The latter need much larger acreages than do more intensive producers.

Markets are absolutely essential for commercial agriculture. Beef cattle, sheep, and certain animal products such as wool, hides, and butter may be transported to market over long distances. In contrast, fluid milk, perishable vegetables, and a fruit such as strawberries require a near-by market or organized, inexpensive transportation to more distant markets. Avoid locating in an area, therefore, that does not have a good market for your particular products or the necessary transportation facilities for marketing them. It matters little how favorable soil and climatic conditions may be; without a suitable market, commercial agriculture cannot succeed.

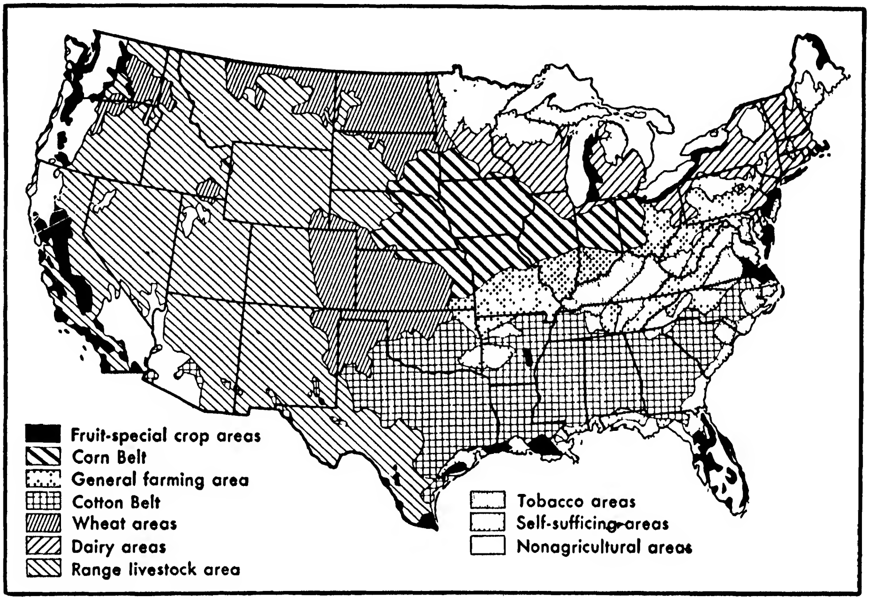

FIG. 15. Leading types of farming in the United States. The principal areas in which different types of farming are carried on are shown. Reference to Fig. 5 will show the relationship between topography and the more intensive types of farming. (*Bureau of Agricultural Economics, U.S. Department of Agriculture.*)

2. Choosing the Community

Choosing a desirable community should be an early consideration in the selection of land for farming and a country home. Congenial,

cooperative neighbors will prove mutually helpful. It is they who will exchange work with you, with whom you will do business, and with whom you will associate in church, educational, and social gatherings. A good centralized school within easy reach is needed for the children. A live community church and other neighborhood social activities, for young and old alike, can contribute much toward satisfactory living in the country. In addition, good telephone service and ready access to electric power are essential.

An all-year road from the home to the community center, church, school, and market is a definite necessity. Not only should there be an all-weather road, but, if in the northern part of the country, one that is kept open in winter by prompt snow removal. Information about roads can be obtained from the highway superintendent or your prospective neighbors. To locate on or near a road upon which there is a public transportation line has many additional advantages. If it goes direct to your community center and market, that is a real convenience. This is true because each adult on the average family farm cannot have a car for his private use, and the children too often need transportation other than to and from school.

Hauling produce to market and supplies to the farm has a definite cost per mile. On the whole, most transportation costs are based largely on distances. Similarly, the cost of other travel is based mainly on mileage. The benefits of locating near your community center, church, and market, therefore, are worthy of consideration. Although an all-weather road is absolutely essential, heavy traffic on a through or truck highway may have real disadvantages to farmers who live directly on them. These disadvantages are particularly acute if the road passes through the farm. Driving livestock across the road and driving teams or tractors to and from fields for preparing the seedbed, planting, cultivating, and harvesting crops are greatly hampered by heavy highway traffic. A good location on an all-year side road may, therefore, have distinct advantages from these standpoints over a location on a heavily traveled main highway.

3. Selecting Well-drained Farm Land

The most productive soil is inexpensive in the long run. You can buy soil fertility far cheaper by the acre than by the ton from the fertilizer dealer. In contrast, land of low productivity is relatively more costly than is more productive land. Such items as fencing and

drainage cost about the same by the rod or mile regardless of the return they may help to produce. The best land is seldom on the market, at least for any length of time, and it must, therefore, be diligently sought for. Land that for any reason is not highly desirable often seeks a buyer for a much longer time than does good land (Figs. 16 and 17 *a* and *b*).

Avoid land that is badly infested with the more troublesome or noxious weeds. Such weeds decrease crop yields and increase the cost of producing many crops. They often decrease the value of hay and grain crops. Weeds increase the cost of cleaning seeds and may even

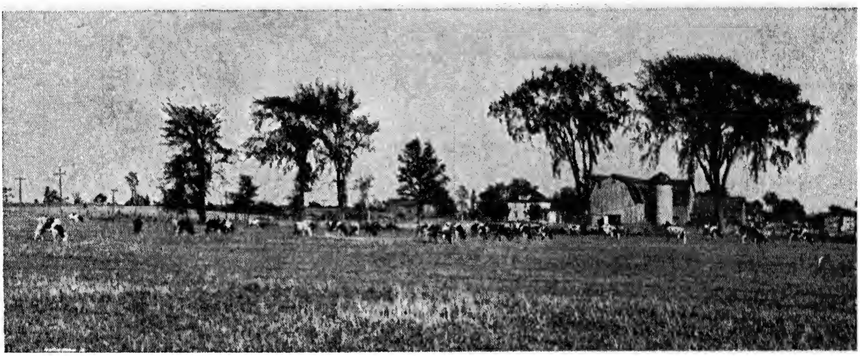

FIG. 16. A good dairy-farm layout in the St. Lawrence Valley of northern New York. These dairy cows are grazing off the second growth of this meadow.

make the seed unsalable. Among the worst weeds are bindweed, or perennial morning-glory, in the Middle West; and Canada thistle, whitetop, or furry cress, and quack, or couch grass, over a wide area in the northern part of the country. Klamath weed and star thistle in the West also may be mentioned.

The size of farm suited to the type of farming chosen and within your financial means and managerial ability to operate requires careful attention and early decision. Many farms will be either too large or too small; some will be of the right size. Well-drained, productive soil that lies well is usually chosen if the price is right.

Judging the Drainage of Soils. Forming an accurate judgment of the degree of natural drainage of soils often is not easy. There is drainage as runoff and drainage through the soil to be considered.

Drainage over the Surface. On land with considerable slope, runoff will be sufficiently rapid so that crops will escape injury except, perhaps, during periods of prolonged moderate-intensity (page 127)

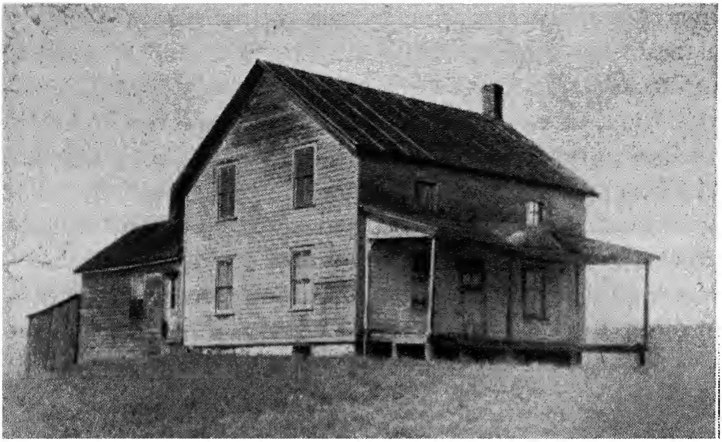

Fig. 17*a*. An abandoned Eastern farmstead. The condition of this farmstead is the result of low income from the land. It failed to support the family and keep the buildings in repair.

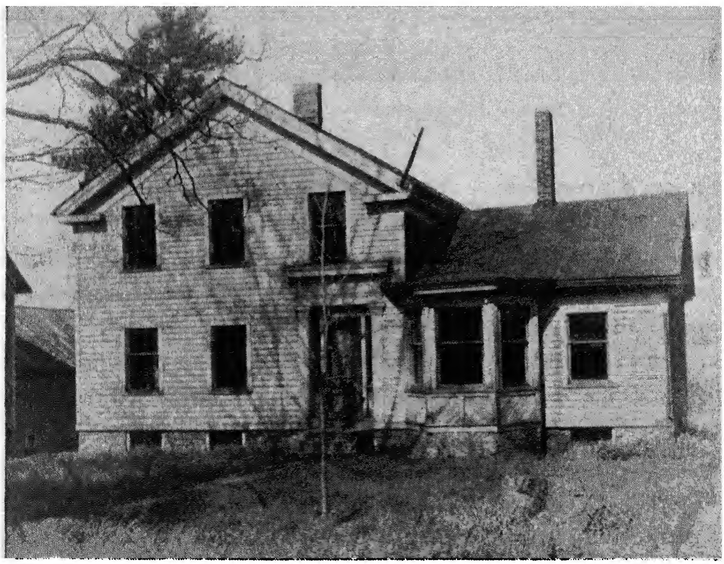

Fig. 17*b*. This attractive house was vacant (May, 1946). It is on a state highway, 2 miles from a thriving village. The reason for vacancy should be determined before buying it.

rains. Then the water may stay too long in the surface soil. Because rain water drives the air out of the soil, the root system of crops may suffer from lack of oxygen. Furthermore, air in the soil is required for the preparation of certain nutrients for crops, and they may suffer from lack of plant food in slowly drained soils after heavy rains. Certain crops turn yellow and finally die if the soil stays wet too long. Similar conditions prevail on slow-draining land that is level or has too little slope for quick surface runoff.

Bear in mind that certain level soil formations possess such good natural drainage that even prolonged heavy rains pass down through them without harm to crops. Such well-drained or, perhaps, droughty soils, however, often do not hold enough water for good plant growth during long rainless periods.

Drainage through the Soil. Usually it is easy to judge the degree of drainage over the surface of the soil, but determining the natural drainage through the soil often is not so easy. In the spring, or soon after heavy rainfall in humid regions, it is easy to distinguish between naturally well-drained and poorly drained soils. Note that the well-drained ones dry off so they can be worked in a fairly short time; the poorly drained ones remain too wet for tillage for much longer periods.

In times of normal rainfall during the growing season the surface of all soils in an area is likely to be in a condition suitable for plowing or other tillage. At this season it is most difficult to judge the drainage through the soil. Examine the soil to a depth of 3 feet or more for indications concerning the approximate rate of drainage. Drainage is usually good through soil materials that have a yellow or yellowish-red color. If you find a hard, compact, gray, or mottled-gray and brownish layer between 8 and 20 inches under the surface, the soil is nearly always poorly drained. Such land usually does not produce large yields of most farm and garden crops and is correspondingly low in value. In general, avoid poorly drained land except for extensive pasture, hay, and forest production. Because of the importance of drainage through the soil and its effect on growing crops, always take into consideration the color of soils, particularly of subsoils, as discussed on page 21, Chap. 1.

4. Judging the Productivity of Land

Under some conditions, forming an accurate estimate of the productivity of land is easy; under others it is a difficult matter.

By the Growing Crops. There is little difficulty in estimating the productivity of good land from the middle to the end of the growing period of crops (Fig. 18). It will be desirable, however, to learn how much manure and fertilizer was used. If crops generally are growing rapidly then and, later in the season, make good yields, the productivity may be judged satisfactory. This conclusion is based on the assumption that rainfall has been normal and that there have been no outstanding unfavorable conditions such as plant diseases or insect injuries. If weather conditions have been favorable and the

Fig. 18. A thrifty crop of cotton in Virginia. The growth of this crop indicates the degree of productivity of this soil and the good management it receives.

crop has been well fertilized and still yields poorly, then the soil presumably is unproductive. Look for other land.

After crops are harvested and during winter and early spring, note the condition of native vegetation or the remains from the previous season's crops. This helps in judging the productivity of land. Wild plants, like cultivated ones, make their best growth on productive soils.

Crops vary in the financial returns they make. Some cost more to produce than do others. Some crops return that cost generously; others do not. It pays to note the proportion of high-return crops that are being grown on the farms under consideration. It is well to do this over several seasons, if possible. If this cannot be done, make inquiry about the yield of crops over several years. If the farm is

being worked by a tenant, capitalizing the rent after taxes, upkeep of buildings and fences, and depreciation over a period of years at 5 per cent gives a fair valuation of farm land.

By Natural Vegetation and Weeds. Many large weeds about a farm and farmstead indicate neglect. Give a farmstead proper care and weeds will have little chance to reproduce and to occupy the land. Weeds make the best growth about manure piles and in land such as the garden where manure has been used freely for many years. Cedar, pines, the hawthorne, the wild rose, and other shrubs encroach on undergrazed or neglected eastern pastures and on old, uncut meadows, especially on unproductive soils. The presence of these unfavorable conditions is a signal for caution. Make a full investigation before investing.

By Trees and Shrubs. Although many trees grow on a wide range of soil conditions, there are evident variations in their thriftiness. Some trees thrive on good soils; others grow fairly well on less productive soils. In general, the trees best adapted to certain soil conditions offer such severe competition to the less well-adapted ones that the latter fail in the race. Thus, the dominant trees may be regarded as representing the natural productivity of the soil. In their area of adaptation, the black walnut, red elm, black and red oak, hackberry, wild cherry, white ash, and sugar maple require productive soils for thrifty growth. And, in general, thrifty growth of these trees may be taken as indicating that the soil is pretty good. If these trees make poor or only fair growth, the soil is likely to be of low productivity. Trees that usually dominate on the poorer soils, however, thrive on good soils if the competition is not too keen for them to establish themselves.

White oak and hickory are found on land that has only fair drainage through the soil, but they grow also on productive soils. Scrub oak, or post oak, grows on soils with slow drainage through the soil. Post-oak soils are seldom cleared, because of their low productivity. Beach and quaking aspen are found on soils that are moist to wet but that do not necessarily lack drainage through the soil.

5. Selecting Land Suited to the Type of Agriculture

It is always advisable to select land that is reasonably well suited to the desired type of agriculture. The soil in certain locations may

be too expensive for some types of farming; other soils may lack the productivity required for intensive types of agriculture.

For Dairy and Livestock Farming. Animal farming is extensive in comparison with fruit or vegetable production. Relatively inexpensive land in fairly large acreages is needed for the production of beef cattle and sheep, and also for dairy farming (Fig. 19). For pasture, in particular, select land that is moderate in cost and fairly

Fig. 19. A Wisconsin dairy farm. The cows are on their way to pasture for the day. A considerable acreage is needed for pasture and hay production for these large dairy herds. (*Wisconsin State Department of Agriculture.*)

well drained. Near large cities, however, if high returns are obtained for fluid milk, intensive dairy farming may be profitable on fairly high-priced land. The returns per unit of investment in land and in soil treatment from beef cattle and sheep are usually lower than from dairy cows. Select fairly low-priced land, therefore, for beef cattle and sheep raising.

For Grain and General Farming. Ideally, somewhat more productive and higher-priced land is sought for grain than for pasture and forage production on the livestock farm (Figs. 20 and 21). Of course, some livestock is kept on the general farm and grain is grown on the usual livestock farm. General farming may include some vegetables and fruits for which high-grade soils are needed. All in all,

FIG. 20. A large "combine" harvesting wheat in Kansas. These implements cut and thresh the grain in one operation. (*A. F. Swanson, Bureau of Plant Industry and Kansas Agricultural Experiment Station.*)

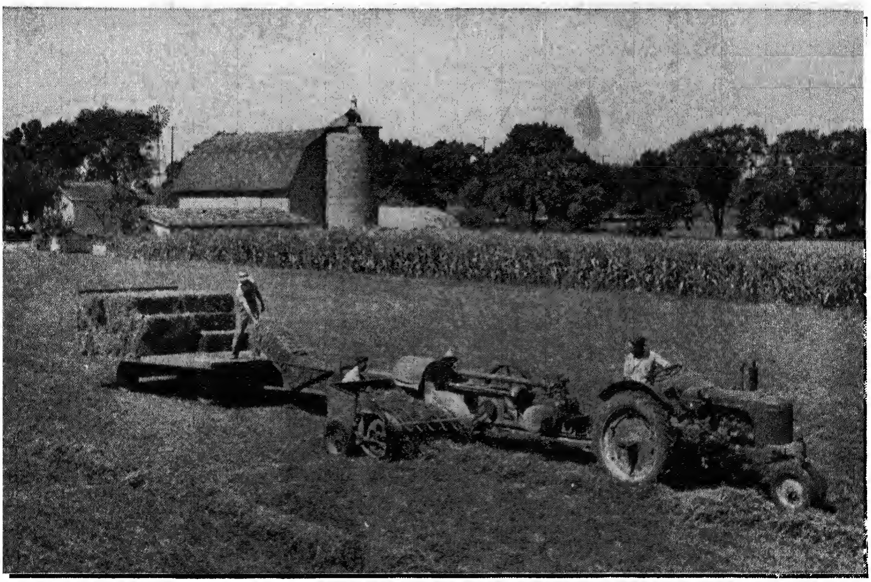

FIG. 21. Harvesting alfalfa on a general grain and livestock farm. Here machinery does much of the heavy work of making hay. (*J. I. Case Company.*)

therefore, rather productive land will be chosen for grain and general farming because of the good returns it can make.

For Producing Vegetables, Fruits, and Flowers. Vegetables, fruits, and flowers require well-drained, productive soils. These crops

FIG. 22. A citrus grove in California. Note the thrifty condition of the trees with part of the crop of fruit still on them. The snow-covered mountains form an interesting background.

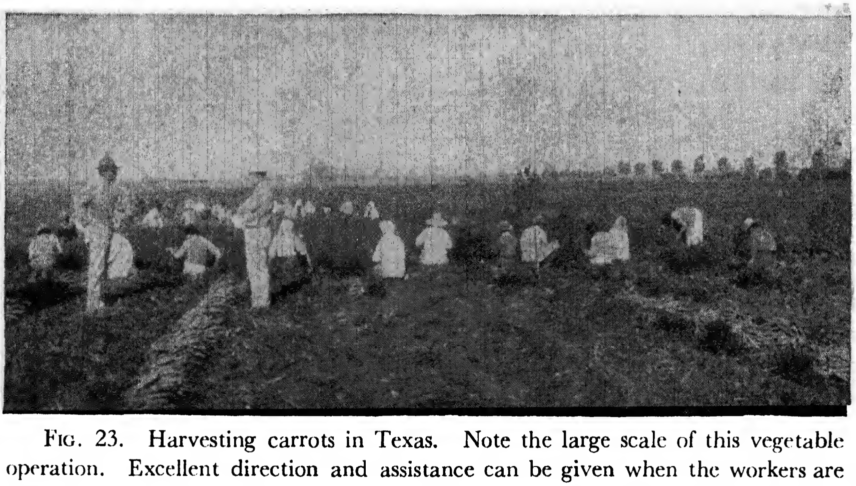

FIG. 23. Harvesting carrots in Texas. Note the large scale of this vegetable operation. Excellent direction and assistance can be given when the workers are kept in fairly close formation. (*S. H. Yarnell, Texas Agriculture Experiment Station.*

generally do not thrive on poorly drained soils. Moreover, well-drained soils are early ones and early soils are required for the first plantings of vegetables in the spring. In addition, much labor is used and large outlays for fertilizer and other treatments are made for these intensively grown crops. Only well-drained soils produce satisfactory returns for heavy expenditures of time, labor, and money.

Well-drained soils permit tillage operations sooner after rains and earlier in the spring than do slow-draining soils. Less time, therefore, is lost in waiting for the soil to dry out so it can be worked. With these high-cost, high-return crops, saving time is especially important. Failure to spray fruits and vegetables at the right time because of the wet condition of slow-draining soil may mean the difference between success and failure in rainy seasons. The well-drained soil, because spraying can be done at the right time, may produce a full crop, whereas poorly drained land, because of delayed spraying, may yield only a poor crop. What has been said about fruits and flowers applies also to vegetables. Because of their many advantages, choose well-drained soils for the production of vegetables, fruits, and flowers (Figs. 22 and 23).

6. Determining the Suitability of Buildings and Other Improvements

Size and Condition of the House. The house, if there is one on the land, should be in good repair and satisfactory in size, not too large and not too small for an average-sized family. Have an experienced builder in whom you have confidence examine the house and estimate the cost, if any, of putting it in good repair. If major changes are planned, determine their approximate cost in advance of actually locating on the farm.

Size and Condition of Other Buildings. Note the size of the barn in comparison with the acreage of cropland. A large barn is a general indication of satisfactory productivity. This conclusion is based, necessarily, on the assumption that the acreage of the farm is the same as it was when the barn was built. Of course, a relatively large barn suggests high productivity of the land, and a small one low productivity. Productivity has not often been greatly increased, but it may have gone down since the barn was built. Poorly constructed, unpainted, tumbledown buildings suggest low productivity of the soil, poor management, or other serious difficulties. They indicate that the land has not produced a fair living for the family and a surplus for the necessary upkeep of the buildings. There are, of course, individual productive farms on which for one good reason or another the owner has put off maintenance and repair of his buildings. He may be using all the income to quickly reduce the mortgage, there may have been expensive illness in the family, or he may be using

profits to educate his children. Information concerning a situation such as this can readily be obtained from neighbors.

A point worthy of first consideration is that a suitable house and farm buildings can usually be bought for a much smaller cash outlay than the cost of building them today. The reason is that materials and labor cost far more now than they did even a few years ago. Present building costs are several times as great as they were when most farm buildings were erected. Naturally, it is of the utmost importance that the farm buildings be reasonably suitable for or readily adapted to the purposes of the new owner.

Extent and Condition of Fences. Much the same idea applies in observing the condition of fences. Fences can be bought installed on the land cheaper than they can be built today. The total difference in cost, however, is far less important with fences than with the house and farm buildings. Nevertheless, well-located, adequate fences in good condition are a point in favor of the farm that has them. Well-kept fences are an indication of good land and of good management on the part of its owner.

7. Securing Information on Available Water Supplies

An adequate and suitable water supply is so essential that seeking information about it is one of the first inquiries to be made in considering any farm, ranch, or plantation.

For the Home. What about the supply of water for use in the home? Is it apparently sufficient for all present and prospective uses? Is the water safe and of suitable quality? In some areas, water is salty; in others it contains objectionable compounds of sulphur. Water often contains iron that may be precipitated upon exposure to the air in quantities that are objectionable in laundering clothing, and in many areas the water is so hard that a water-softening outfit is needed to make the water suitable for family use. The cost of making water suitable for human use therefore, may, be great.

In certain areas, water is difficult to obtain for one reason or another. On relatively narrow ridges between fairly deep valleys, the underlying rock or other material may be such that wells of good water in sufficient quantity are sometimes not obtainable. In other areas, on land well above streams, the soil material is so porous that it is not possible to obtain adequate supplies in wells of moderate depth and at a moderate cost. In certain such areas, rain water must be

stored in cisterns for home use. Even after it has been filtered, this soft water is not wholly suitable for all purposes in the home. Moreover, there is always some danger that if cistern water is used freely the supply may be exhausted during long periods of low rainfall.

In many areas of deep, underlying gravels, a relatively shallow well in the water-bearing strata supplies enough suitable water. Springs in the near-by upland often supply adequate water of suitable quality for all purposes.

It is in semiarid areas, especially, that a good water supply must be assured if a farm is to be suitable for a home. To haul water for domestic use in tanks or barrels from some distance away is time-consuming and quite unsatisfactory. On some of the mesas (tablelands) in the West, the irrigation water is unsuitable for livestock or home use. There, hauling water must be resorted to, and settling on a farm in such areas might prove too costly and unsatisfactory in the long run.

For Livestock and General Farm Uses. An adequate supply of suitable water for livestock is no less vital than for use in the home. Although good water is required for livestock, water of a quality that is not suitable for the home or dairy may be used. Water from streams, springs, or ponds is often used for livestock. If no other source is available, surface water may be caught and stored in ponds for livestock. In many situations, ponds provide a relatively inexpensive water supply for stock. In semiarid areas, however, make certain that the pond is large enough to hold sufficient water for long periods. Evaporation from the surface of ponds and lakes wastes much water in the drier areas.

For Irrigation. A study of the growing-season rainfall by 10-day periods will show how often to expect droughty periods in a humid area. The calendar month is too long for drought-period studies because occasionally all of the rain of a month falls at one or the other end of the period. In some years the rainfall may come at the beginning of July, for instance, and no more may fall until the final week in August. In this situation, both July and August, however, would have average rainfall according to the records, yet a dry period of 7 weeks is possible. Such misinterpretation is avoided by using 10-day periods for drought studies.

During the hotter months drought periods of sufficient length to cause serious injury to crops are not uncommon in most years in many

parts of the humid section of the country. Consequently, there is a rapidly growing interest in irrigation, or the application of supplemental water, during such periods in normally humid areas. It is for food crops that it is most essential to determine in advance whether there are sources of abundant supplies of suitable water for irrigation (Chap. 4). Water that is suitable for domestic use or for livestock is perfectly good for irrigating crops.

In irrigated sections, especially in the Intermountain Region, the water right that goes with a farm is about as important as the land itself. The irrigation ditches developed by irrigation companies vary in the places at which they tap the main stream, usually a river, and in the amount of water they carry. The farther down the river the main ditch is taken out, the less chance of getting the full amount of irrigation water, particularly in dry seasons. The same is true of the location of a farm with respect to the main irrigation ditch. Although the shares in a water company may call for the same number of inches of water, the farmers near the head of a ditch usually have a distinct advantage. The location of land with respect to the source of water, therefore, deserves careful consideration. In irrigated sections, be certain a farm has legal rights to adequate water for irrigation and a supply of water suitable for livestock and for domestic use.

8. Checking on Climatic Conditions

Rainfall, temperature, frost, and other climatic data may be found in state and federal publications on agriculture and climate, and are usually available in county soil-survey bulletins.

Length of Growing Season. Obtain data on the period between the average date of the latest killing frost in the spring and the first killing frost in the fall. This period is commonly spoken of as the growing season. The true growing season, however, varies with different crops. Crops that are not sensitive to frost begin growth before the latest killing frost in the spring and continue to grow after a killing frost comes in the fall. Hot-weather crops, in contrast, do not begin to grow until some time after the last killing frost in the spring and should mature before the first killing frost in the fall. Such crops do not use the whole growing season. There is, therefore, a wide difference in the length of the actual period for growth of frost-resistant and hot-weather crops; that of hot-weather crops is much

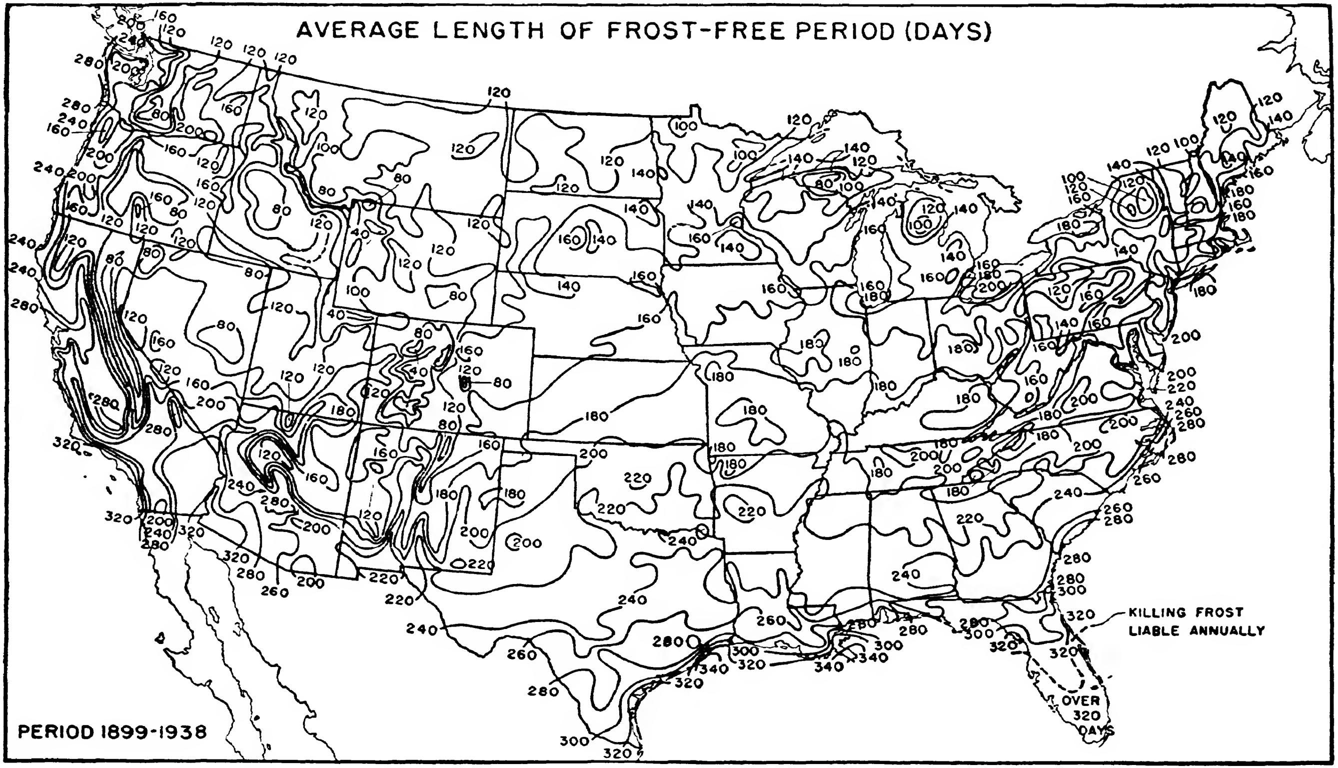

FIG. 24. Average length of the frost-free period in the United States. The lines show the boundaries of the areas by 20-day intervals; the figures on the map are the length of the frost-free period in days. This information should be helpful in reaching a decision on what to grow in any section of the country. (*U.S. Weather Bureau.*)

shorter than for cool-weather ones. Nevertheless, it is the number of days between killing frosts that is shown in Fig. 24. On a small-scale map like this, only approximate figures are shown, yet they should be of value in determining what crops can be grown successfully in the area under consideration.

The extremes of summer heat and winter cold and average summer temperatures will be helpful in determining which crops can be grown to best advantage. Hot-weather crops will not be planted in the low temperatures of early spring, and vice versa. Instead, cool-weather crops will be grown in areas of low summer temperatures. Ask neighboring farmers about local frost dates and obtain a copy of Weather Bureau reports for the area. These should help any farmer in planning what crops to grow, when to plant, and when to harvest in order to escape injury to the plants.

Rainfall in the Growing Season. You will wish to know what the average annual precipitation is, how much of it falls as rain, and how much as snow. Precipitation includes all water in rain, sleet, hail, and snow. Snowfall is of particular importance in the drier areas and is of interest also in humid regions. Find out about the approximate average growing-season rainfall from neighbors and Weather Bureau records. Learn also whether or not summer rainfall is enough for good crop yields in the area under consideration. If not, determine what can be done by suitable soil-management practices to enable crops to make the most efficient use of what moisture is available.

In dry areas, winter rains may be absorbed and stored in the soil for use by crops the following growing season. Solidly frozen soils, however, cannot absorb much water.

SUMMARY

1. Decide on the type of farming and the area in which to farm. Much of the success and the happiness of the family will rest upon making the right choice.

2. Choose the type of community where you can enter wholeheartedly into its activities and its very life.

3. A good road past the house to market and community center is essential. A suitable market is essential for all types of commercial agriculture.

4. Financial success depends largely on the selection of the right kind of land. Naturally good drainage through the soil is most important because

you can't improve drainage through the soil. If, however, land is too nearly level for good surface drainage, ditches can be installed rather easily for surface drainage.

5. Select land with high natural productivity, because good land is usually a bargain. It would be costly to make poor land productive.

6. The appearance of crops and trees, shrubs, and other vegetation, including weeds, will help you to choose land with high natural productivity.

7. After you have decided upon the type of agriculture in which to engage, select land that is suitable for it. The cost of a farm ought to be correlated with the expected returns from the type of farming that is to be followed on it.

8. More land is needed for livestock or grain farming than for fruit, vegetable, or flower production. For these high-value crops, choose the best soil available, even if it is relatively high priced.

9. Because buildings on farms can be purchased for much less than the cost of erecting them today, get a good set of farm buildings with the land if possible.

10. Consider first the house. Make certain that it is in good repair or can be restored to good condition at a reasonable cost. The cost of improving the house or other buildings is part of the cost of the farm. The house should be of a size suitable for an average farm family and the helpers needed.

11. If the barn is not suitable for dairying (in case that is the desired type of farming) can it be changed to a good dairy barn at reasonable cost? If not, look at other farms. Consider also the condition of the barn and other buildings.

12. Fences, too, are important; it is desirable that they be in good repair, because you will be very busy the first year on any place without having to rebuild the fences that same season.

13. Learn about the water supplies for domestic use, for livestock, and for the irrigation of crops—especially food crops.

14. Check on climatic conditions. Make sure that the average growing-season rainfall and irrigation water, if used, are sufficient for the production of satisfactory crop yields.

15. Determine from Weather Bureau publications how often droughts of more than 10 days' duration come in the growing period. If droughts occur in most years, find out about a source of water for supplemental irrigation, at least for the garden. Irrigation, when needed, helps to assure a good, regular supply of home-produced food.

16. Inquire about the time of the latest killing frost in the spring and the first one in the fall. The length of the frost-free period largely governs the crops that you can grow successfully on any land.

3. Tilling and Managing Crop Soils

FARMERS stir the soil in many ways with many different implements. They till the soil because crop plants cannot compete with weeds on an even basis. Cultivated plants must be given great advantages over plants which grow wild if crops are to produce food and clothing materials for man, and feed for livestock. Although tillage methods and implements have been greatly improved since the day of the forked-stick plow, tillage by means of modern plows, seedbed preparation, and cultivation of crops still continue to bring sweat to the brow of man. Tilling the soil is presented in this chapter under the following major activity headings:

1. Analyzing the Benefits of Tillage
2. Plowing Soils
3. Preparing the Seedbed
4. Tilling with Seeding Implements
5. Cultivating Growing Crops
6. Using Weed Killers

1. Analyzing the Benefits of Tillage

By *tillage* is meant all of the ways of turning, loosening, cultivating, and compacting the soil. Only the more widely practiced methods are discussed here. Certain means of tillage are more widely used in some areas than in others. The emphasis, therefore, may well be on specific methods practiced in the locality.

Loosening the Soil. Few of the ordinary field and garden crops thrive in compact soils—those that are hard, or in a poor state of tilth. Farmers make great expenditures in time and power to loosen the soil properly in preparation for the planting of crops. The soil can be loosened with a variety of implements that differ considerably in construction, depending on the work for which they are designed.

Controlling Weeds. Many farm and garden crops are unsuccessful in their struggle to compete with weeds and, therefore, much work must be done to control the weeds. Plowing is one of the best ways to control perennial weeds, or those that grow from roots that live in the soil from year to year. Such weeds often become well established in meadows and pastures. The bindweed, Canada thistle, and quack, couch, or witch grass are extremely troublesome in such a cultivated crop as corn; they require special attention.

Plowing meadows and pastures temporarily controls goldenrod and whitetop, or daisy. Bindweed, however, is not greatly damaged by plowing without additional treatment.[1] Go over the land about every two weeks during the growing season with an implement of the duckfoot type, as this weakens the plants. It may be necessary to treat the soil in this way for two consecutive seasons to kill this pest. Set the blades of the duckfoot so the ends overlap in order to be certain that all bindweed roots are cut off and the top growth killed each time the land is cultivated. If even a few vines escape, this weed will infest a field again in a few years.

Many weed seedlings are killed during seedbed preparation. In fact, the ideal time to begin weed control in cultivated crops is during the preparation of the soil for planting. At that time there are no crop plants to interfere with thorough, rapid cultivation. Almost complete control of all weeds that have already germinated and come up is possible then. Later the crop plants require protection and this slows down the work of weed control.

Mixing Crop Remains with the Soil. Many coarse crop remains or residues such as corn, cotton, broomcorn, and kafir stalks interfere with the preparation of the soil for the crops that follow them. The stubble from grains and trash from other crops are something of a nuisance on the surface because they interfere with tillage operations. If a hay crop follows small grain, the trash is raked up in the first cutting of the hay crop. Such materials reduce the selling price if not the actual feeding value of hay. Mix residues with the soil; they rot quicker and are of greater value to crops in humid areas than if they are left on the surface. Avoid leaving coarse residues on the surface as they interfere with planting, with obtaining a good stand of the crop, and also with weed-control practices.

[1] HANSON, N. S., F. D. KEIM, and D. L. GROSS, Bindweed Eradication in Nebraska, *Nebraska Agricultural Experiment Station Circular* 50, 1943.

To control the corn borer, plow down all stalks, weeds, and other coarse trash as early in the spring as soil conditions permit. Cover cornstalks completely, as this is essential for even moderately good control of the corn borer.

Aerating the Soil. Air, as already stated, must get into the soil to displace gases that are harmful to plants. This interchange is called *aeration* or ventilation of the soil. Turning the soil with plows and stirring it with harrows exchange fresh air for much of the gases that are in the soil. Seeds must have oxygen from the air for germination; plant roots require oxygen for healthy growth; and soil organisms cannot do their work without oxygen. In addition, the nodule organisms on the roots of clover, alfalfa, and other legumes must have nitrogen in order to fix it for the benefit of nonleguminous crops. The exchange of the carbon dioxide in the soil for fresh air, therefore, is highly beneficial to crops. Aerate the soil; crops cannot make good growth in the absence of suitable aeration.

Absorbing Rain Water. Loose soil absorbs water quickly during moderate rains, but compact soil, as in early spring, absorbs water slowly. Much water, therefore, is lost as runoff from soils before they are loosened in the spring. Extremely heavy rains, however, may cause heavier loss of soil from plowed than from unplowed soil. A few heavy rains compact the soil so that it will need to be loosened again if it is to absorb rain water quickly. Absorption of water is essential for the benefit of the crop later in the season when rainfall may not be plentiful, and water that is taken up by the soil does not carry away organic matter, plant food, and the soil itself. Follow practices that increase absorption of rain water.

2. Plowing Soils

Good plowing may be done with any one of several types of plow; any plow used should be run at a uniform depth and width if smooth plowing is to be done. Depressions and ridges result from shallow plowing in some places and from "cutting and covering" in others or from attempting to plow several inches wider than the plow can properly handle. Such unevennesses increase the work of seedbed preparation and may even require an extra harrowing to produce a suitable seedbed. And an extra trip over the land takes time and calls for expensive labor.

Selecting Plows. The plow is the leading implement in use for loosening soils. Several implements, however, are used on a small scale for the same purpose as the plow. Some of these implements and their action will be described.

Moldboard Plows. Most of the plowing in the humid part of this country is done with moldboard plows (Fig. 25). The rolling colter, or jointer, or the two combined in one are used to cut the soil on the

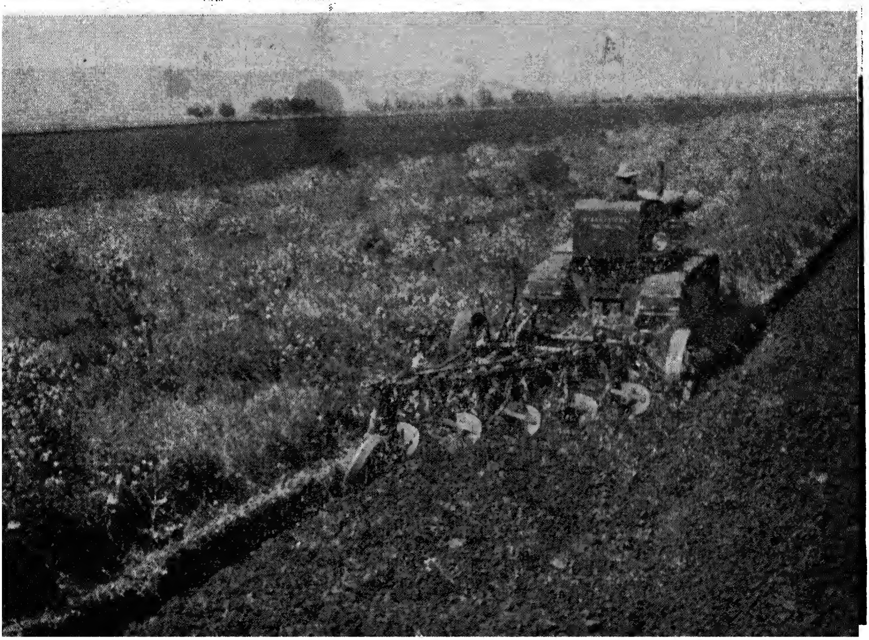

FIG. 25. Moldboard plow. The moldboard plow has been widely used in humid agricultural areas. Plows hold a place that is secure for the present, although future developments may replace them with more efficient implements. (*International Harvester Co.*)

land side and to aid in covering trash. This is largely the work of the jointer. On sod land the jointer turns the live sod over on the furrow slice and the whole is turned over. The live plants or those that might grow later, particularly if wet weather follows plowing, are turned under and smothered out completely. Growing grass is seldom found on land that was plowed with the jointer (Figs. 26 and 27).

There are three types of moldboards in general use; the *general-purpose*, *sod*, and *stubble* moldboards. The general-purpose moldboard

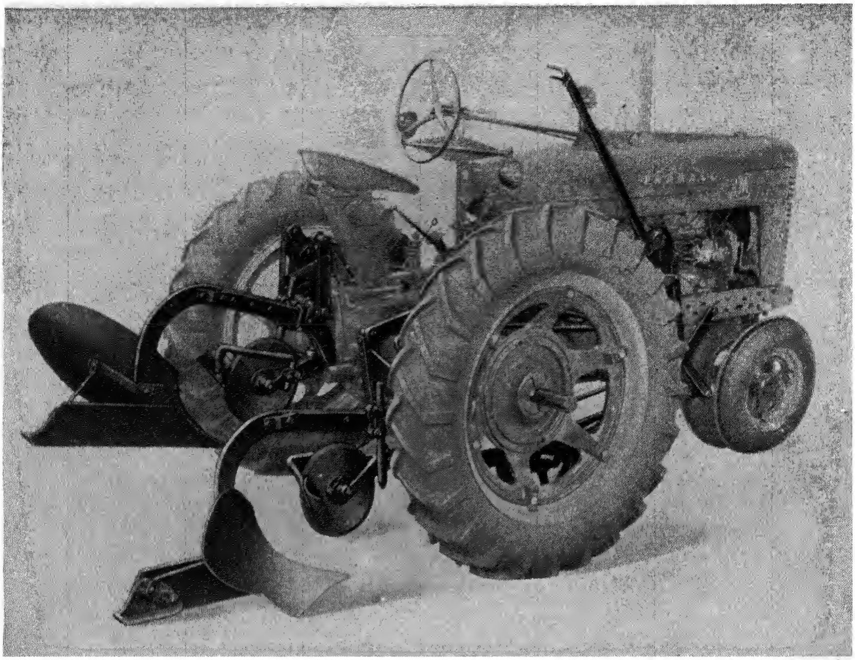

FIG. 26. Single-bottom two-way plow. Direct mounting of the plows has many advantages for easy turning. Plowing is done back and forth in the same furrow. No ordinary dead furrows result—a distinct advantage on rolling lands. Note the jointercolter on this plow. (*International Harvester Co.*)

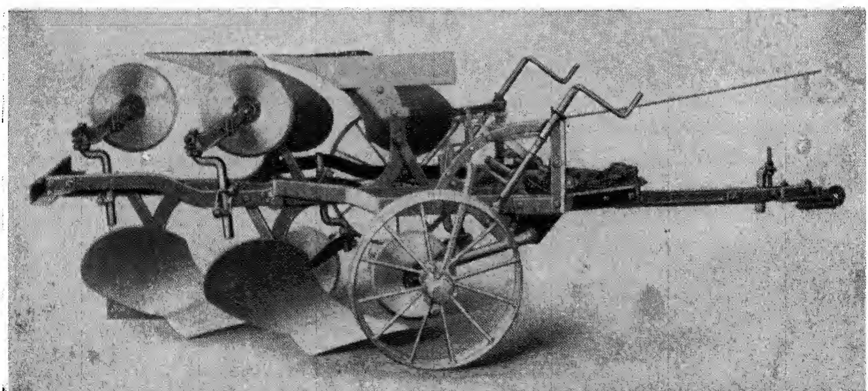

FIG. 27. Double-bottom two-way plow. This plow is for use on larger areas with more powerful tractors than that shown in Fig. 26. A pull on the rope permits the two-way plow assembly to turn over so as to plow back and forth in the same furrow. As with the single-bottom type no dead furrow is made. The plain rolling colter is used on this plow. *International Harvester Company.*)

serves fairly well in sod, in corn, cotton, and grain stubble, and in soils following vegetables and potatoes." Its curvature is intermediate between the others and is used on small farms that need but a single plow.

The sod moldboard has a moderate degree of curvature so that it will not break the furrow slice and leave it too rough for easy working down to prepare the seedbed. The sod moldboard, if properly adjusted, should turn the furrow slice at a slope about midway between on edge and perfectly flat.

Fig. 28. Disk plow. The disk plow does good work on stubble or open land. It is not ordinarily well adapted for plowing stiff sod land. (*The Oliver Corporation.*)

The stubble moldboard has the sharpest curvature of all and is used for pulverizing the soil and covering trash suitably. Soils that have become compacted since the previous plowing need to be well pulverized in order to produce a suitable seedbed at little cost.

Disk Plows. Disk plows have been in use over a period of years but do not seem to have become generally well established (Fig. 28). These plows work well in stubble, clover, or clean soil but do not perform so well in stiff sod. There the furrow slice is laid over in "kinks" and is difficult to work down into a suitable seedbed. One advantage of this plow is that all the weight is carried on the wheels instead of sliding on the bottom of the furrow. Plow sole does not

develop with disk plows. In fact, the plow sole produced by other implements can be broken up by running the edge of the disks an inch or two into the plow-sole layer.

For dry-land farming, the disk plow is useful because it does not pulverize the soil too much. It should aid in preventing or reducing the blowing of soils in arid and semiarid regions, simply because it leaves the soil somewhat rough rather than pulverized. Moreover, this plow may be adjusted to set the furrow slice on edge and thus expose some stubble or other fine trash between furrow slices. In

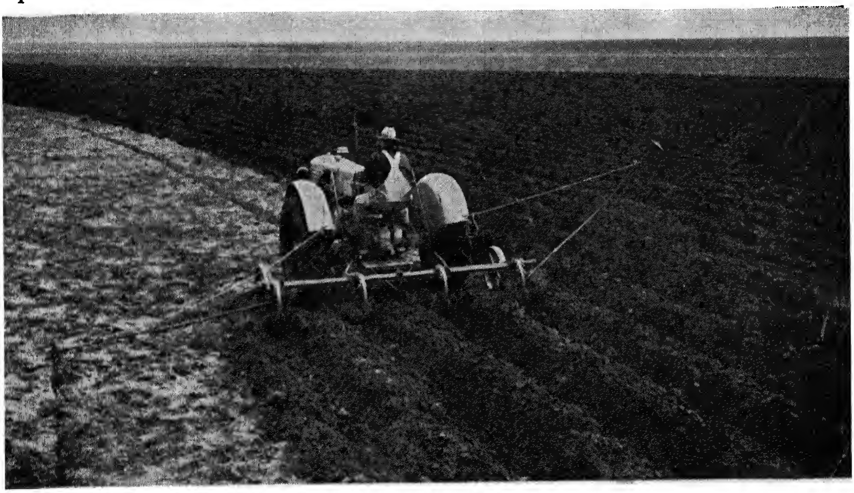

FIG. 29. The lister. Essentially the lister is a double-moldboard plow that throws the soil in both directions and leaves an open furrow. Crops are seeded in the bottom of the furrows. The lister has long been in use in dry-farming areas and is coming into use in humid areas for corn. (*Minneapolis-Moline Power Implement Co.*)

that way, the stubble aids in checking blowing and helps to direct water into the soil between furrow slices. Both of these aids are generally beneficial to soils and crops.

Listers. Listers, also known as "middlebreakers" and "ditchers," are double-moldboard plows that open furrows by throwing the soil in both directions at the same time when pulled across the field (Fig. 29). Such crops as corn and some grain sorghums are planted in the bottom of the furrow. In cultivating crops thus planted, the soil is gradually rolled toward the plants in the furrows until the surface is nearly level again. Thus, the roots are fairly well down in the soil, and the crop usually withstands drought better than it does in seedbeds prepared in other ways. The lister is much used in dry-farming areas

and is coming into use, at least experimentally, in parts of the humid region. Here it is hoped that this implement may also be of value in the control of soil erosion.

Subsoil Plows. The subsoil plow consists of a shoe or hook that runs in the bottom of the ordinary plow furrow. Its purpose is to break up any plow sole and to loosen the soil to a depth of several inches below the usual depth of plowing. The subsoiler is not intended to throw any soil out of the furrow or even to mix the bottom of the furrow with the plowed soil.

It is in the drier areas that benefits from subsoiling should be expected. Widespread experimental work with subsoilers on 12 experimental stations in 9 states shows little benefit.[2] These workers did not obtain increases in crop yields as a result of subsoiling in the 12 areas that they studied. Depending somewhat on how it is done, subsoiling costs nearly as much an acre as ordinary plowing. The writer took part in experimental work with subsoiling that was carried on in Illinois. The surface soil was gray with a tight or hardpan layer at about 13 to 16 inches under the surface. No increase in yield was obtained by subsoiling in Illinois. On the basis of the work done 2 decades ago, subsoiling is not recommended. Experimental trials under present-day conditions, however, should be made.

Deep Tillers. Deep-tilling implements have been on the market for the past 25 years. One of them was a double-disk plow; the rear disk worked in the furrow made by the front disk. The purpose of the rear one was to loosen the soil to greater depth and more thoroughly than is done by the subsoiler. Considerable mixing of subsurface soil with topsoil took place in its operation. The cost of plowing with this implement was practically twice as great as plowing with an ordinary moldboard plow. Plowing to this additional depth did not increase yields in Illinois.

A later and entirely different type of deep-tilling machine is the Killefer (Fig. 30). It consists of one or more blades with a shoe at the lower end and is pulled through the soil to loosen it at intervals. It requires a heavy tractor to draw it because of the heavy draft of such an implement. The operator can vary the depth as may be desired. The Killefer machine has been used in the West more than

[2] CHILCOTT, C. E., and JOHN S. COLE, Subsoiling, Deep Tilling, and Soil Dynamiting in the Great Plains, *Journal of Agricultural Research*, Vol. 14, pp. 481–521, 1918.

in the Middle West, East, or South. For breaking up a soft chemical hardpan layer, implements of this general type can serve a real purpose. In clay soils, however, any effect is entirely temporary.

Deep stirring below the ordinary plow depth consumes much time and takes much power; it is costly. It cannot be used to advantage in soils that contain sizable stones, especially flat ones, or that contain ledges of solid rock. The Killefer is different from the deep-tilling

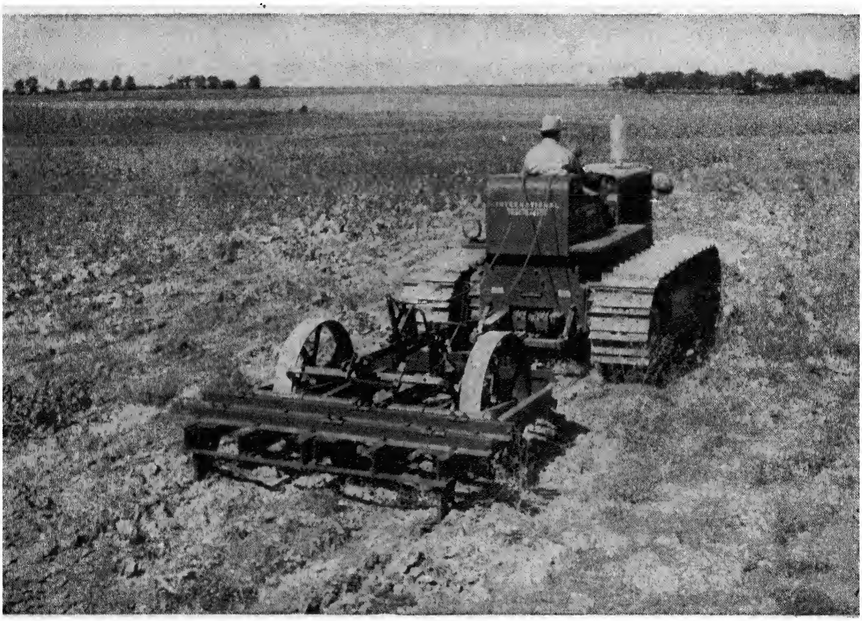

Fig. 30. Deep-tilling machine or chisel. Strong blades loosen part of the subsurface soil. Experimental work in the East has not shown this work to be advantageous.

implements that have formerly been used in humid areas; experimental use of it, therefore, is warranted. Because of the high cost of operation, it is not recommended for general use at present. That must await favorable results from carefully conducted trials of the Killefer under varying soil conditions.

Rotary Tillers. A number of tilling implements that employ the principle of loosening the soil by means of rapidly rotating spring-steel hooks are on the market. It is claimed that once over the land with this implement produces a finished seedbed. Only a fair degree of coverage of trash is accomplished. The use of these implements

does not appear to be feasible on any kind of sod. Any clover, rye, rye grass, or other live plants that may be left on the surface take root after rains and grow like weeds in the planted crop. In an area where potatoes are grown year after year on the same land without cover crops, rotary tillers may be serviceable. Potatoes are planted so deeply that the extreme looseness of the seedbed is not objectionable.

FIG. 31. A rotary tiller. Rotary tillers have been used for gardens and similar-sized areas for many years. A field-tractor size is now coming into production. The soil is loosened by tines or blades that are rapidly rotated. Once over the land produces a fine but very loose seedbed. Natural settling before seeding is desirable. (*Rototiller, Inc.*)

For most vegetable and field crops a firmer seedbed is needed than that produced by the rotary type of tilling implements (Fig. 31). For small gardens the smaller types of rotary tillers are used, but the seedbed is objectionably loose. It needs to stand for a week or two to settle naturally or to be settled by rains. If this is done, weeds get a start and must be killed by some type of harrowing before the small-seeded vegetables are planted.

Weeds must not get a head start on garden crops. If they do, the problem of weed control is made far more difficult than if seeds are planted in weed-free soil. And if harrowing to kill weeds is required

after settling of the soil, seedbed preparation, obviously, is not accomplished in one operation. Once-over seedbed preparation, therefore, is an oversimplification that is seldom practicable in gardening in humid areas. Nevertheless, the garden size of rotary type of tiller has a place in greenhouses and in gardens that are too large for hand spading.

Choosing the Time of Year to Plow. Plowing may be done at any season when soil conditions permit. In the northern states spring and fall are the principal seasons of plowing. In exceptional years a little plowing is done in December and January, but most plowing is done in the spring. A large acreage, however, is fall plowed.

Land for wheat and rye should be plowed in late summer, although much wheat is seeded after harrowing only, if it follows a clean-tilled crop such as beans, and sometimes corn or other crops. Plow as early as possible after the previous crop has been harvested to produce the best yields of wheat. One reason for this is that the loosened soil has time to be firmed by rains and natural settling. Some weed seeds germinate and the plants are killed by the tillage of final seedbed preparation. Also, soil organic matter and trash, that have been plowed in, decay so that the plant food in them is ready for use by the young seedlings. This plant food helps the wheat to make a vigorous growth and to go through the winter in good condition.

Fall plowing is desirable on well-drained, heavy soils that contain a good supply of organic matter. Repeated freezing and thawing of such soil bring about *granulation*, a condition favorable for crop growth. If water stands on fall-plowed soils in late fall or early spring, however, *puddling* instead of granulation occurs. In that condition the soil often needs to be plowed again in the spring. The time spent in fall-plowing such areas is all but lost. It is better to let such soil wait until spring to be plowed.

In normal seasons there is some advantage in plowing in the fall because fall work is usually less rushing than spring work. Yet, more total work is needed to prepare the seedbed on fall- than on spring-plowed land. It is necessary, therefore, for the farmer to balance the advantages against the disadvantages and decide which time is best in a particular situation. If early seeding in the spring is exceptionally important it will probably pay to do the little extra work. Fall-plowed land can be harrowed before it is dry enough for spring

plowing; harrowing takes less time than plowing and then preparing the seedbed. Some gain in time of seeding early spring crops, therefore, is likely if land is fall-plowed.

There is some danger of blowing and washing of fall-plowed soil on sloping lands. Sandy land should be plowed at approximately right angles to the prevailing wind direction. If serious blowing is threatened, it is best to leave the soil protected over winter by the vegetation that was on it. Sod or stubble land with part of the stubble exposed between furrow slices, particularly if covered with snow some of the time, does not blow seriously.

If sod is plowed uphill and left rough, much of the water from rain and snow finds its way into the soil through the grass between the furrow slices. The rough sod catches and holds snow that checks freezing below the plowed soil. Much water is taken up by the soil through these spots that remain unfrozen. Less water, consequently, is lost as runoff and less erosion follows. Soil that has little trash on it is subject to washing if fall-plowed. If the slope is steep or the soil washes easily, wait until spring to plow. There is less danger of serious damage by puddling in fall than in spring plowing.

Spring plowing is best done early, after the soil is dry enough to be stirred safely. If the soil slips off the moldboard slick and shiny, wait a day or two for the soil to dry before plowing. Because the moldboard is curved to pulverize the soil, it also breaks down the granules in soils that are too moist. Puddling heavy soils in the spring, especially late, is nearly certain to injure crops throughout the season, and possibly for a year or two afterward.

Early spring plowing of soils in suitable condition permits highly desirable natural settling of the soil. Such soils seldom need to be rolled to compact them. Late-plowed soils, especially if they are a little dry, are so loose that rolling to compact them is necessary. Dry, heavy soils that have been allowed to become low in organic matter may turn over lumpy. It is nearly impossible, without waiting for rain, to produce a satisfactory seedbed from such cloddy soil. Rain, however, does melt down such clods, but it then is usually rather late for seeding crops.

Sometimes it is feasible to disk ahead of plowing if the season is getting dry. Disking may hold enough moisture to make good plowing possible. If the lower part of the furrow slice is cloddy, rolling with the cultipacker (Fig. 35) breaks the lumps and packs the soil.

Sometimes when plowing is done after the soil has become dry it is good practice to roll it with the cultipacker at the end of each half day to crush clods before they dry out and become hard. Once they have hardened, producing a satisfactory seedbed is difficult.

Deciding on Depth to Plow. The depth to plow, both from the standpoint of costs and from that of yields, deserves consideration that it does not always receive. When plowing was done with oxen

TABLE 4. CROP YIELDS AN ACRE FROM VARIED DEPTHS OF PLOWING IN OHIO*
(Average for 12 years)

Crop	Depth 7½ inches	Depth 15 inches	Ordinary 7½ inches subsoiled
Corn, bushels	61 13	59 47	61 33
Oats, bushels	49 00	49 29	49 05
Wheat, bushels	31 50	31 49	31 65
Clover, pounds	5,300	5,060	5,200

* Forty-first Annual Report, *Ohio Agricultural Experiment Station Bulletin* 362, p 11, 1922.

TABLE 5. EFFECT OF SUBSURFACE TREATMENT IN ADDITION TO PLOWING IN ILLINOIS*
(Bushels per acre)

Plowing and other treatment	Corn (9 crops)	Soybeans (7 crops)	Wheat (6 crops)	Sweet clover seed (6 crops)
Plowed 7 inches	40 2	16.3	13 5	3 68
Plowed and subsoiled to 14 inches	41.9	16 2	12 9	3 65
Deep-tilled to 14 inches	37.4	15 2	10 8	3 18
Dynamited—plowed 7 inches	40 3	16 4	11 7	4 25

* SMITH, R S Experiments with Subsoiling, Deep Tilling, and Subsoil Dynamiting, *Illinois Agricultural Experiment Station Bulletin* 258, p 163, 1925

and later with horses and mules, 4 or 5 inches was a common depth. With the development of multiple hitches for horses and later the tractor, deeper plowing could readily be done. Sometimes a selling point for the tractor was that deep plowing could easily be done. Deeper plowing requires more power and costs more. Does it pay? A study of the data available is interesting. Tables 4 and 5 give the results of plowing at various depths.

The yields produced by different depths of plowing at the Ohio Agricultural Experiment Station show no advantage for plowing

deeper than 7 inches. Work in Illinois showed lower yields of corn from plowing shallower than 7 inches. Ordinary disking in the Middle West instead of plowing has produced considerably lower yields of corn. Plowing a little shallower than average some seasons and a little deeper in others may avoid the development of the plow sole. Available data show that the largest yields are obtained from plowing 6 or 7 inches deep, and the cost of plowing increases considerably with greater depths.

Subsurface Soil Treatment. Some years ago various types of subsurface soil treatment were advocated. Experimental work was conducted to get the facts. Now different types of deep soil treatment again are being urged and some farmers are trying out new ideas. This is as it should be. Try them in an experimental way, but make certain what the comparative yields really are. Only in that way and from experiment-station trials can the facts be learned.

The dynamiting of subsoils was widely advocated after World War I. To answer farmers' questions the Illinois Agricultural Experiment Station made comparisons of ordinary plowing with additional subsurface treatment. The soil was one with a hard impervious layer several inches below the ordinary plowed soil. The yields of 28 crops in 9 years are shown in Table 5.

Subsoiling after plowing 7 inches deep, deep tilling to 14 inches, and dynamiting in addition to plowing 7 inches deep were compared with plowing 7 inches deep. The charges of dynamite were placed at distances of 1/2 rod apart on some plots and 2/3 rod on others. From the data in Table 5 it is clear that under the conditions of this test, crops were not benefited by subsurface soil treatment. Even so, the cost of subsoiling and deep tilling was twice that of plowing 7 inches deep, and the cost of dynamiting was nearly 10 times that of plowing. In the absence of favorable experimental results, these subsurface soil treatments cannot be recommended in the humid area of the United States.

3. Preparing the Seedbed

In general a good seedbed is firm underneath and has a mellow, weed-free surface. On sandy soils it may be necessary to roll in order to obtain the desired firmness. A suitable seedbed is more difficult to produce on heavy soils. Too much stress cannot be placed on the need for having the seedbed free of weeds. Even if there are no

weeds actually growing, their seeds are in the soil, moist, all ready to germinate. Crop seeds are planted dry and must absorb moisture before they germinate. The weeds, therefore, have an advantage over crops, especially over slow-germinating ones.

Crops vary in their seedbed requirements. Alfalfa does best if the soil is particularly firm underneath so long as the surface is favorable

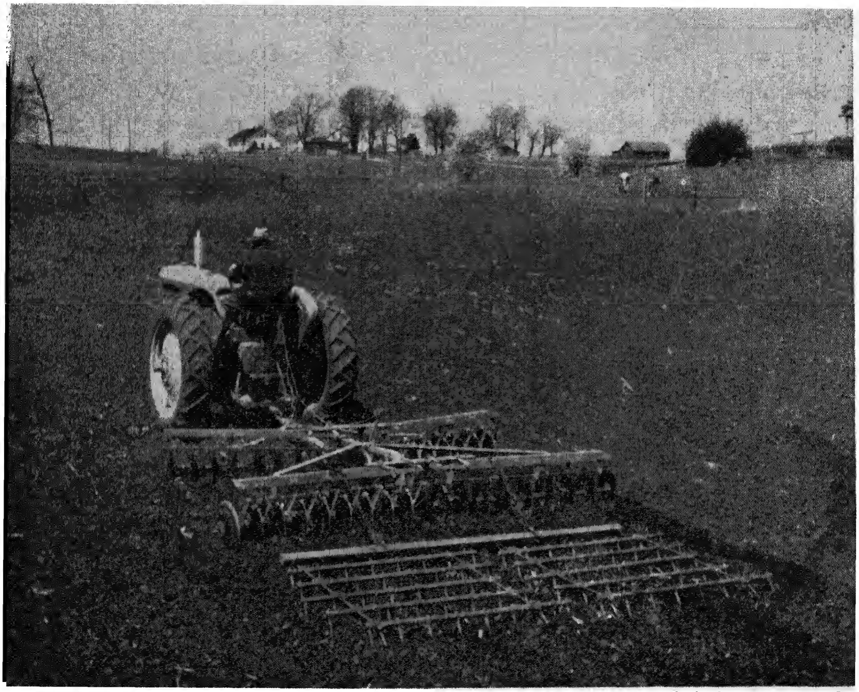

FIG. 32. Disk harrow and peg-tooth harrow. The double-disk harrow works best on soils that are free of large flat stones. It is used to *loosen* the surface soil while the peg-tooth harrow *breaks up* the lumps and makes a finer seedbed. These harrows are also used separately. (*The Oliver Corporation.*)

for germination. Small-seeded vegetables require a fairly fine seedbed immediately over the seeds. Corn and grains come up through a thin or not too hard and thick crust. Beans and the legumes in general have great difficulty coming up through a hard crust. For these and other small-seeded crops a very finely pulverized seedbed in silt loams, clay loams, and other heavy soils is distinctly undesirable in humid areas. A heavy shower puddles a finely pulverized soil and a crust forms, through which small-seeded crops and leguminous

crops come up with difficulty. Shallow planting may aid in obtaining fair "come-up" under these conditions.

Although plowing is the beginning of seedbed preparation, this term is usually applied to the work that follows plowing. Many implements are needed for preparing suitable seedbeds for various crops on different kinds of soils.

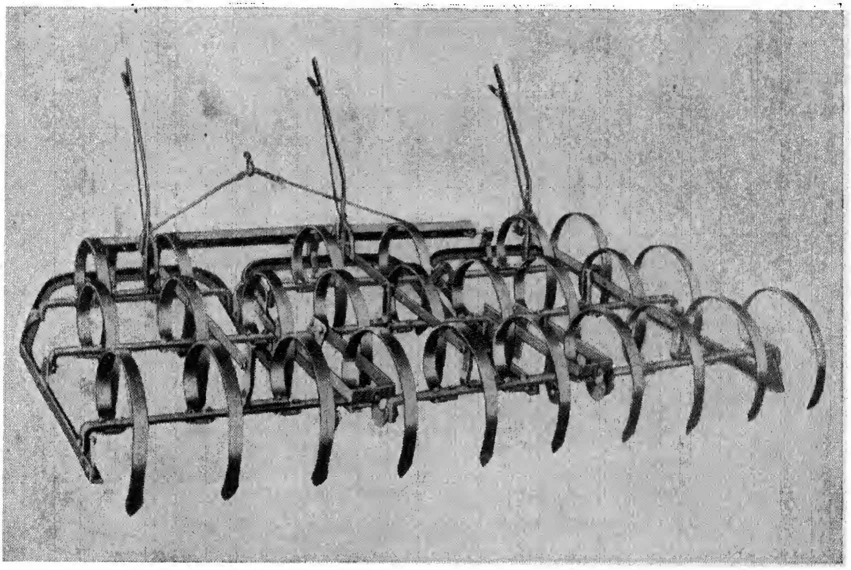

FIG. 33. The spring-tooth harrow. The spring-tooth harrow is widely preferred in the East, in part because of the stony condition of many soils. The spring-tooth harrow collects trash and drags weed roots about fields; the disk harrow does not do this. (*Deere and Co.*)

Selecting the Implements. Insofar as they are available, use the right implements to do the job desired. Harrows are widely used; in fact they are probably indispensable.

Disk Harrow. In the Middle West, with its immense acreage of almost stone-free soils, the disk harrow (Fig. 32) is most widely used on fall-plowed land and on badly compacted spring-plowed land. The disk is used much less in the East with its stony soils. In the South, however, the disk is popular. It may be substituted for the plow on muck and sandy soils. Keep in mind the fact, however, that the disk harrow leaves a pulverized, loose surface which, in the Great Plains country, tends to blow.

Spring-tooth Harrow. The spring-tooth harrow (Figs. 33 and 34) is widely used in the East on stony soils, particularly those that contain flat stones. This harrow, like the disk harrow, may be adjusted for different depths. Under most conditions it does a good job of leveling and loosening the surface soil. It is used on fall-plowed land, sod, and spring-plowed land. It is run shallower in spring- than in fall-plowed land. The disk harrow is probably better on rather

FIG. 34. The field cultivator or "weed-hog." This implement is a sturdy, mounted spring-tooth harrow. The depth of tillage is definitely regulated and it can do heavier work than ordinary spring-tooth harrows. (*The Massey Harris Co.*)

heavy soil than the spring-tooth because the latter does not pulverize the soil sufficiently for many purposes.

Peg-tooth Harrow. The peg-tooth harrow is sometimes called a spike-tooth or smoothing harrow. It is widely used in the Middle West to smooth and to fine the surface of spring-plowed land. It is used after the disk harrow on fall-plowed land to fine the surface to the desired degree. One objection to the spring-tooth and peg-tooth harrows is that they spread the roots of perennial weeds. Typical of

this difficulty is quack grass in the East, couch grass in Canada, and morning-glory in the Middle West. The disk harrow is free of this criticism. All of these harrows compact loose soils to some extent.

Rollers. Smooth and corrugated rollers are in general use. The smooth roller is used to press stones down out of the way of the mower on meadows, and, similarly, for the binder or combine in connection with spring or winter grains. It is used to firm the surface of newly plowed soil. A criticism is that it packs only the immediate surface of the soil. Also, the smooth surface it makes crusts over readily on heavy soils and permits water to run off easily.

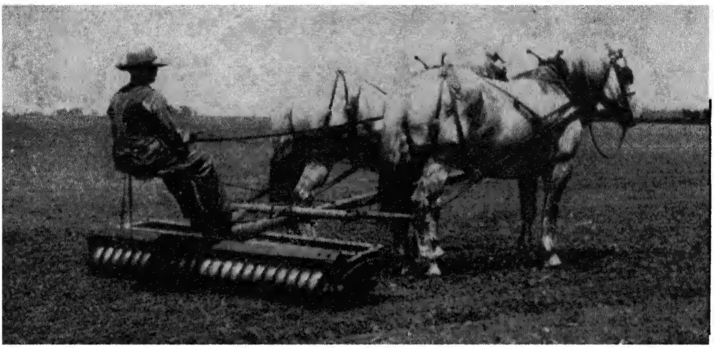

FIG. 35. The corrugated roller. This roller is particularly well adapted for firming the entire plowed soil. Moreover, it leaves alternate ridges and furrows that help to avoid the crusting effect of intense rains on the smooth surface of heavy soils.

The corrugated roller, or cultipacker, carries its weight on the sharp edge of the disks or wheels (Fig. 35). This enables it to crush clods near the surface and to pack the soil down in the furrow slice as much or more than on the surface. Such compacting improves the condition of the plowed soil by closing any large open spaces. Rolling improves conditions for root development and for retaining moisture. On sloping fields, rolling on the contour with this implement tends to hold water against runoff and this lessens loss of soil by erosion.

4. Tilling with Seeding Implements

Seeding implements stir the soil much as do some of the harrows. This stirring may well be regarded as part of the seedbed preparation and control of weeds. The grain drills are particularly effective. The disk drill (Fig. 36) works much the same as the disk harrow,

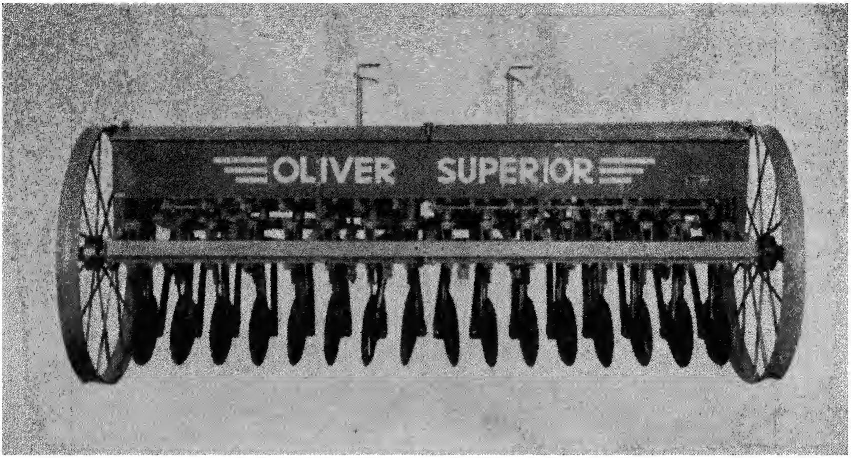

FIG. 36. The disk drill. This drill works best under the same conditions as the disk harrow. In addition, it accomplishes a good deal of tillage. It does not drag trash or weed roots about fields. (*The Oliver Corporation.*)

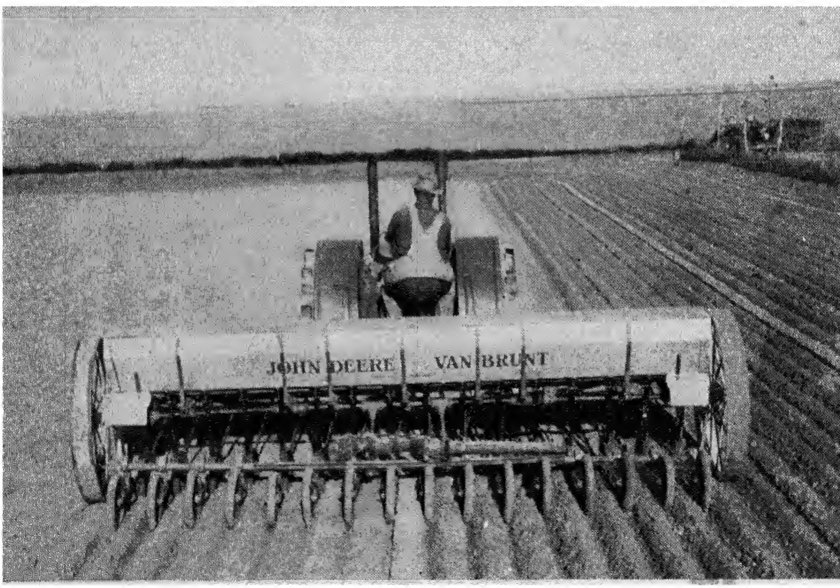

FIG. 37. The furrow drill. Disks open a furrow in which the seed is planted. Such furrows on the contour hold water for the crop. Across the main wind direction, they aid in controlling the blowing of soils. (*Deere and Co.*)

although usually shallower. The hoe drill goes about as deeply as the disk drill for the purpose of covering the seed. Its stirring of the soil is comparable with that of the disk drill. The hoe drill has the disadvantage of dragging weed roots and scattering them over fields. The furrow drill (Fig. 37) is used in dry-farming areas for seeding grain. There, it is necessary to conserve water and to check wind erosion.

Most planters, including potato, corn, cotton, bean, and kafir planters, and plant setters such as those used for cabbage and tomatoes, stir the soil near the seed. This stirring checks weed growth near the seed or plants. Cover the wheel tracks of planters, especially if they run up- and downhill, by means of a shallow harrowing with a smoothing harrow. Doing this eliminates the tracks that act as a place for water to collect and start gullying.

5. Cultivating Growing Crops

Selecting the Implements. Crops are cultivated, or intertilled, by means of a number of suitable implements. Each of them is better suited to one type of crop or soil than are others. Implements used are the peg-tooth harrow, weeders, including the rotary or flexi-hoe, and the shovel, disk, and blade cultivators.

Weeders. The peg-tooth harrow is used on corn and a few other crops for which it is not too severe. If plants are very tender, put off its use for a few days until the plants are more resistant. Sunshine tends to toughen them and enables them to stand more punishment. Harrow winter wheat and rye, as harrowing benefits these crops.

The weeder and rotary hoe (Figs. 38 and 39) have somewhat wider use than the harrow because they are not so rough on the plants. The weeder works well on corn and similar crops, and on soybeans during the middle of the day. Soybeans are not so tender and subject to damage then as early in the morning, when they are particularly tender. These wide implements save time by cultivating more rows at a time than the regular cultivators.

Cultivators. Shovel cultivators (Fig. 40) with two, three, or four shovels on each gang are widely used for corn, potatoes, beans, and cabbage as well as for other field-grown vegetables and crops. Shovels do satisfactory work on a wide range of soils—sandy ones, silt loams, and clayey soils. This type of cultivator is better adapted to stony soils, either rounded or flat stones, than are other types. One

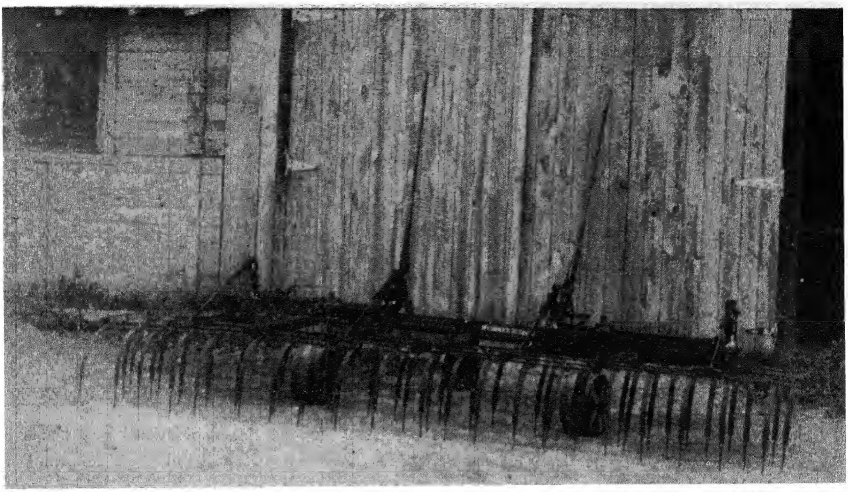

FIG. 38. The weeder. The weeder comes in the one-horse type and in a larger mounted type like this one. It is particularly useful for killing weeds in crops that are too small to cultivate with larger implements. Also, it is a good implement for covering meadow seedings.

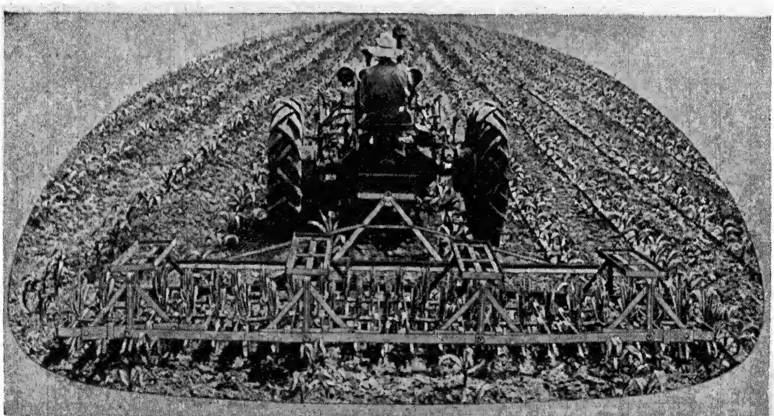

FIG. 39. The rotary hoe. This is particularly useful for breaking the crust after heavy rains. Also, it is an excellent weed killer to use when the plants of a crop like corn are too small for ordinary cultivation. (*Blount Plow Works.*)

criticism may be made of the shovel cultivator: it spreads weeds by dragging them on the shanks of the implement.

The disk cultivator is used to a moderate extent. In the first cultivation the soil is thrown away from the plants to avoid covering

them. This leaves the plants on a narrow ridge that may dry out and reduce the stand. In the second and later cultivations the soil is thrown toward the row. The second cultivation levels the land and the third builds up something of a ridge along the row. In contour-planted crops on sloping land a ridge is advantageous, even though level cultivation is advised on level fields. The disk has an advantage over the shovel cultivator in fields that have many morning-glories, much quack grass, or weeds that may be spread by dragging them

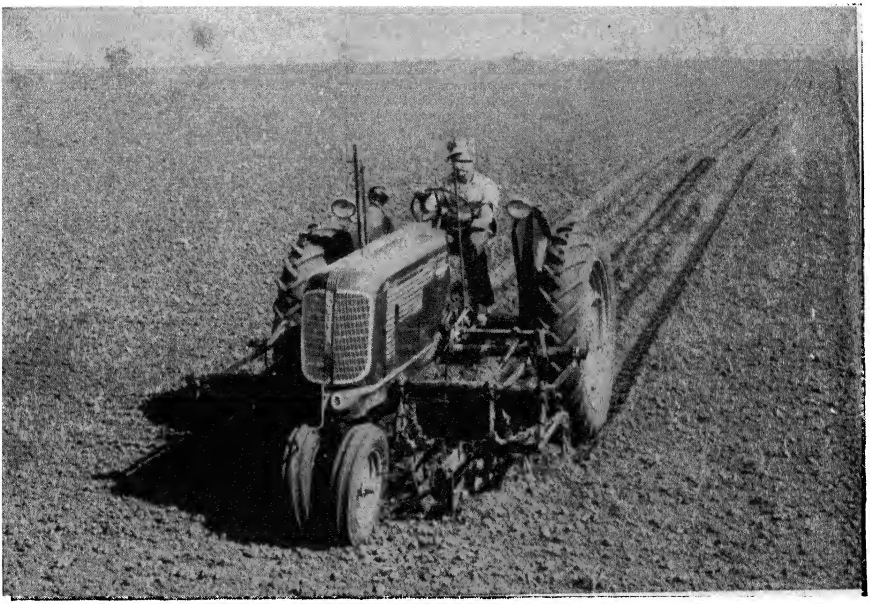

FIG. 40. The shovel cultivator mounted on a tractor. Here is a two-row shovel cultivator in action. It is necessary to follow the pairs of rows that were planted together. (*The Oliver Corporation.*)

about the fields. The disk cultivator serves better where stubble or other trash has been left on the surface as a mulch to help to check soil erosion.

Blade or surface cultivators have two blades on each side of the row. These blades are run under the surface where they scrape off the weeds. The blades move only a little soil toward the row. Blades work ideally in stone-free soils or those that have only small stones and in soils that are free of large weeds. If weeds have become well established during a wet period, use the shovel or disk; it is better than the blade cultivator to bring weeds under control. Moist,

coarse trash is likely to catch on the blades and cause some delay in cleaning them. For strictly shallow surface cultivation the blades do excellent work under favorable soil conditions. Some farmers use the shovels for the first two cultivations and the blades for the third and any later one. Blades probably cause less injury to the roots of crops.

Beating rains often produce a hard crust on the surface of heavy soils. If the crop is too large to use the weeder or rotary hoe to break the crust, use the shovel or disk cultivator; it is better under such conditions than the blade cultivator. The rotary hoe does break crusts to excellent advantage.

Determining the Depth for Cultivation. The depth to cultivate corn was widely discussed and many experiments in the cultivation of corn were started in the 1880's. The Missouri, Illinois, Ohio, Iowa, and New York (Geneva) experiment stations studied cultivation of corn during that period. The study in Illinois was repeated 30 years later with and without plowing and, in addition, cultivated corn was compared with corn in which the weeds were allowed to grow. These later yields obtained in Illinois are given in Table 6.

TABLE 6. EFFECT OF TILLAGE AND CULTIVATION ON YIELDS OF CORN ON UNFERTILIZED LAND*

Plot number	Tillage and cultivation	Urbana, average for 8 years		Fairfield, average for 4 years
		Yield of shelled corn, bushels	Yield expressed as percentage of plot 4	
1	Not plowed or cultivated, weeds scraped off with a hoe.	36.0	80.4	38.7
2	Plowed, seedbed prepared, weeds scraped off with a hoe.	48.7	108.7	115 5
3	Plowed, seedbed prepared, weeds allowed to grow.	7.0	15.6	34 5
4	Plowed, seedbed prepared, three shallow cultivations .	44 8	100 0	100 0

* Adapted from WIMER, D C, and M B HARLAND, The Cultivation of Corn, *Illinois Agricultural Experiment Station Bulletin* 259, pp 180 and 190, 1925

Two points are clear from this work: It is necessary to plow or otherwise loosen the soil for corn. Less than three-fourths of a crop was produced without plowing. Allowing the weeds to grow in

competition with corn reduced the yield to one sixth of a crop. Shallow scraping produced one twelfth more corn than even shallow cultivation.

In similar work started in 1916 on fertilized land at the same station, scraping with a hoe and blade cultivation each produced 53 bushels of shelled corn to the acre. The shovel cultivator produced 51 bushels, and with weeds allowed to grow, only 7 bushels to the acre. One point is outstanding—corn cannot compete with weeds in the average season. It fared a little better against weeds in dry seasons, but in wet ones the seed corn was scarcely reproduced. The best cultivation for corn controls weeds but does not disturb the corn roots. In wet years, if weeds get a good start, controlling them is essential even if some corn roots are injured by fairly deep cultivation.

Vegetables fail utterly if the weeds are allowed to grow undisturbed. At the Cornell University Agricultural Experiment Station,[3] hand cultivation and scraping were compared. Only celery showed a higher yield from cultivation than from scraping with a hoe.

Determining the Benefits of Cultivating Crops. Formerly it was believed by many farmers and other workers that cultivation saved large quantities of moisture. Later experiments, however, have shown that the different depths and methods of cultivating crops do not markedly affect the moisture content of the soil. The principal result of cultivation of crops in both humid and semiarid climates is control of weeds. Cultivation on heavy lands, however, also benefits crops by aerating the soil. Cultivating silt loams and lighter soils is unnecessary in dry periods when weeds make little growth. Cultivation helps somewhat in the absorption of rain water in humid areas and of irrigation water wherever it is used. It should be fully understood that the control of weeds by cultivation or otherwise is absolutely necessary for vegetable crops, cotton, corn, and potatoes; in fact, for all intertilled crops.

6. Using Weed Killers

Farmers have long recognized the absolute necessity for weed control in cultivated as well as noncultivated crops. In fact, the loss suffered by farmers because of weeds has been estimated to be several billion dollars a year. Such crops as sugar and table beets, carrots,

[3] THOMPSON, H. C., Experimental Studies of Cultivation of Certain Vegetable Crops, *Cornell University Agricultural Experiment Station Memoir* 107, 1917.

parsnips, onions (seed), lettuce, and other vegetables cannot compete unaided with weeds. Crops in which the young plants are small and grow slowly in the early spring, and in which weed enemies grow rapidly, are most likely to benefit from the new methods of weed control. Weeds are most easily killed when small and succulent.

Poisons and acids have been used to kill various objectionable plants. Nonpoisonous sulfamate (Ammate) is used to kill poison ivy

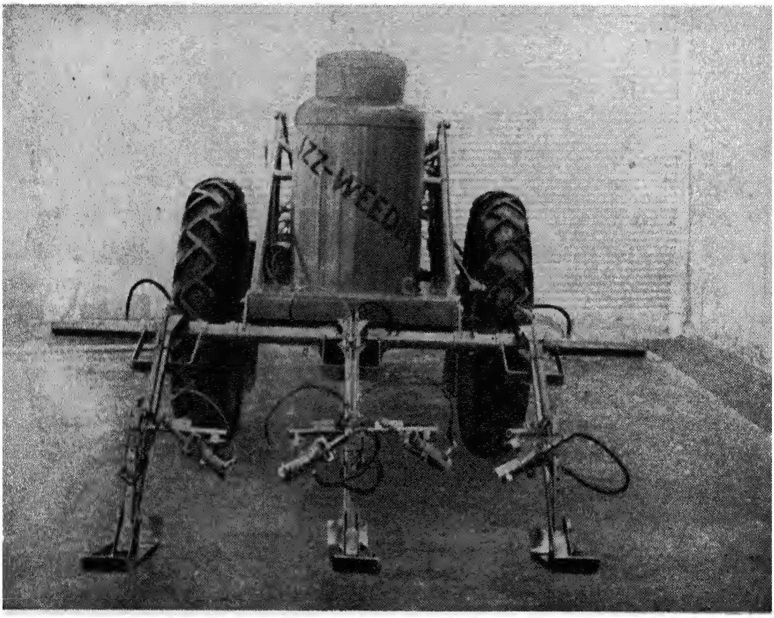

FIG. 41. Late-model, two-row Sizz weeder. The crop plants are less sensitive to the heat than are the young weeds. The latter, therefore, are killed. (*Fijelen Research and Development Co. Manufactured by the New Holland Machine Co.*)

and chokecherry. Most plants that grow in association with these and other noxious weeds also are killed by the sulfamate. It is rather expensive for extensive use.

Killing Weeds with Light Oils. Light oils are used as selective weed killers. Certain economic crops tolerate these oils but many weeds are killed by them. Most of the annual weeds in carrots and parsnips are killed by an application of these oils. The roots of Canada thistle and quack or couch grass are not killed, but the oil kills the aboveground growth. Carrots, celeriac, taprooted parsley, parsnips, and celery are tolerant of the oil. Ragweed, wild carrot, and some grasses are not killed by the oil.

The oils used are such dry-cleaning fluids as Stoddard Solvent and kerosene that contains 12 to 15 per cent of aromatics.

Eighty, or sometimes as much as 120 gallons an acre are used in fan-type spray nozzles. These must be carried at such a height that the oil covers all the area between the rows. A pressure of 100 pounds gives a coarse spray that is desirable for killing weeds by this method. Use only one oil spray on bunching carrots, because a

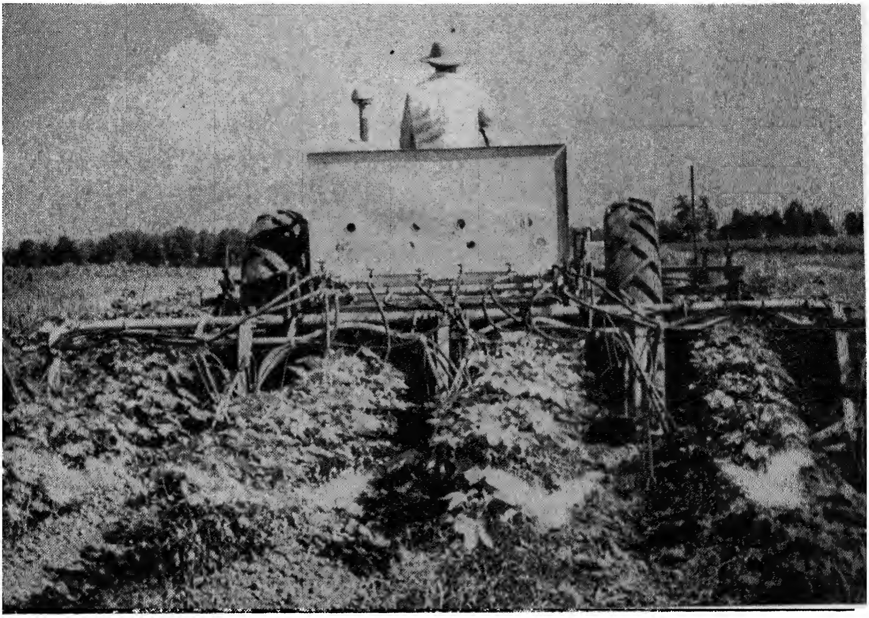

FIG. 42. The flame weeder in action in Mississippi. Here the high-temperature gas flame is directed at the base of the rows of cotton. The stems of the cotton plants endure heat that kills the weeds. This may prove an inexpensive way of controlling weeds in crops that are uninjured by the heat. (*Fijelen Research and Development Co.*)

month is required to rid the carrots of the oil they absorb. Until experimental work has established the facts, do not use oil sprays on vegetables generally. Beets, peppers, asparagus, cabbage, onions, turnips, spinach, and lettuce have been injured by oil sprays.

Killing Weeds with Plant-growth Regulators. Plant-growth regulators have been used as weed killers during 1944, 1945, and 1946 with excellent results. The one commonly used is 2, 4–D (2, 4–dichlorophenoxyacetic acid). In contrast to the oils, of which 80 to 100 gallons are used to the acre, 2½ to 5 pounds of 2, 4–D an acre is

sufficient. Kentucky bluegrass is uninjured by 2, 4–D but many common lawn weeds are killed by it. Tomatoes also are killed by very dilute concentrations of this hormone. Restrict its use to the situations outlined by the manufacturer and the experiment-station workers.

Killing Weeds with Flames. The flame weeder was first used on cotton in Mississippi in 1944, and on corn in New York in 1945 (Figs. 41 and 42). Success depends on applying heat to weeds at a time when they are too tender to withstand it. Flame weeding must be done when the crop plants are more resistant to heat than are the weeds.

Flame cultivation has been successful on weeds 3 to 4 inches high in corn that is about 6 inches tall or more. If the large weeds are not killed, their growth is checked to the advantage of the crops. Up to the present time flame weeding has not been successful on spinach, cabbage, soybeans, peas, and beans. Further testing and experimental work is needed before wider use of the flame weeder can be recommended.

SUMMARY

1. Broadly, tillage includes all methods of seedbed preparation and cultivation of crops. For most crops, it is necessary to loosen the soil before seeding. Also, loosening it helps to control perennial weeds. Plowing mixes manures and crop remains with the soil. Loosening the soil brings about aeration and helps in the absorption of water.

2. For loosening the soil there are many implements. Among them are three distinct types of plows: moldboard, disk plows, and listers; the latter, however, is similar to the moldboard plow. Rotary tillers work on a different principle, but their purpose is the same as that of the moldboard plow. Subsoil plows and deep tillers are used to loosen soils below the ordinary plow depth.

3. Plowing is done in spring and fall in the North, and also in the winter in parts of the South. In the North, fall plowing possesses some advantages over spring plowing; also some disadvantages. Much of the land, however, is spring-plowed. Under some conditions fall-plowed land other than sod, particularly in the South, may be subject to erosion.

4. Experimental results in several states show that corn and similar crops require loosening of the soil to a depth of 6 or 7 inches. How the loosening is done is not as important as the fact that it must be done.

5. Such subsurface treatment of the soil as subsoiling, deep tilling, and dynamiting, although costly, have failed to increase crop yields.

6. Seedbeds are prepared with different implements for different crops. The spring-tooth harrow works best in stony soils and is a useful implement particularly in silt loams and heavier soils. The disk harrow does excellent work but is not so good as the spring-tooth harrow in stony soils. This is particularly true in soils that have flat stones. The peg-tooth harrow is most useful in fairly heavy soils that are relatively free from stones and when the main purpose is to level the soil and to break up the lumps.

7. The corrugated roller is preferred for firming or compacting the entire furrow slice. The smooth roller compacts mainly the immediate surface of the soil. This roller, however, is excellent for pushing stones down out of the way in the spring in meadows and for fall-grain fields. Harvesting is more easily done if the stones are out of the way.

8. Such seeding implements as disk and hoe drills accomplish nearly as much seedbed preparation as the disk or spring-tooth harrows. This stirring is to be regarded as part of seedbed preparation.

9. Two purposes are served by the cultivation or intertillage of crops: Controlling weeds in general and, in addition, aerating heavy soils. Select the type of cultivator that works best in a particular soil for the crop that is being grown. The weeder or peg-tooth harrow is excellent for crops such as corn in the early stages of its growth. The weeder may be used until corn is about 1 foot high.

10. Shallow cultivation is best for corn and many other crops, under favorable conditions. Deeper stirring, however, is required if weeds have made a growth of two inches or more as often happens in wet periods. The weeds must be killed because intertilled crops cannot compete with weeds. Cultivation, therefore, must be done to a depth that will control weeds as completely as conditions will permit.

11. Practicable, inexpensive methods of killing weeds with oil sprays are coming into use for carrots and parsnips. Exceedingly small quantities of the growth-regulating substance, 2, 4–D, are in successful use for killing many weeds in lawns. Flame weeders are successfully used on cotton and corn but not on certain vegetables. Follow directions. These new methods may prove to be of great service to agriculture in general.

4. Controlling Water in Soils

THE need for the control of water in soils differs with rainfall, soil, and cropping conditions. In humid areas, drainage is the outstanding need in periods of heavy rainfall, yet in droughty times conserving water or putting it on is also of real service to crops. In dry-farming regions the water that falls must be saved and moisture losses held as low as possible. In semiarid areas, where water for irrigation is available, the farmer must apply it in order to produce crops. Thus water-control problems vary widely under these different conditions. In discussing the control of soil water, an understanding is needed of the relation of water to soils and crops. Controlling water in soils will be presented under the following activity headings:

1. Classifying Soil Water and Following Its Movement
2. Improving Crops by Draining Land
3. Selecting Ways of Draining Land
4. Planning and Laying Out a Drainage System
5. Estimating the Cost of a Drainage System
6. Selecting Drain Tile
7. Ditching for Tile Drains
8. Laying Drain Tile
9. Keeping a Drainage System in Operation
10. Reducing Loss of Water from Soils
11. Determining the Relationship of Soil Water to Plants
12. Dry Farming
13. Irrigating Crops in Regions of Low Rainfall
14. Irrigating Crops in Humid Areas

1. Classifying Soil Water and Following Its Movement

Water may be considered in relation to the way it is held by the soil or to the way that it moves in the soil. This may be illustrated by means of a simple experiment (Fig. 43). Fasten several thicknesses of cheesecloth over the end of a glass tube about 1 inch in diameter and about 5 feet long. Fill the tube with soil that is free of

clods as large as ¼ inch in diameter and place the lower end of it in water. Water will rise in the soil. In a sandy soil the water rises rapidly, but it does not rise very high. In a heavy soil such as a clay loam, the rise is very slow and not very high. In a soil of intermediate texture, such as a silt loam, the water rises more rapidly than in the clayey soil but less rapidly than in the sandy soil. In the silt loam,

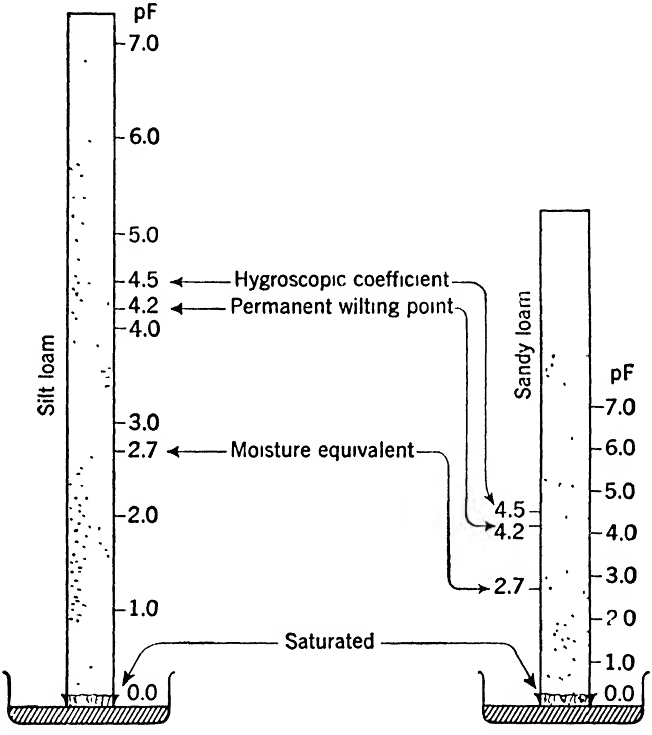

FIG. 43. Water relationships in silt loam and sandy loam soils.

water eventually goes much higher than it does in sandy or clayey soils. In some of his early work the writer found that water rose as much as 9 feet in a silt loam in 3 months.

Gravity is constantly pulling downward on this water in the soil, yet the water rises and then is held there. Except for some force that acts upward, or in the direction opposite to gravity, the water could not rise in the soil. This upward force is the surface tension of water and may be expressed in terms of "pF."[1]

[1] The expression pF is similar to pH (p. 168) in that *p* signifies that the value is not arithmetic but is instead a logarithmic one. F represents force or energy, here the tension

When the tube is lifted from the water a little drainage takes place, but most of the water is held in the soil. The water at the extreme lower end of the tube is only barely held and is said to be at pF 0.0. A short distance up the tube, a force equivalent to the weight of a

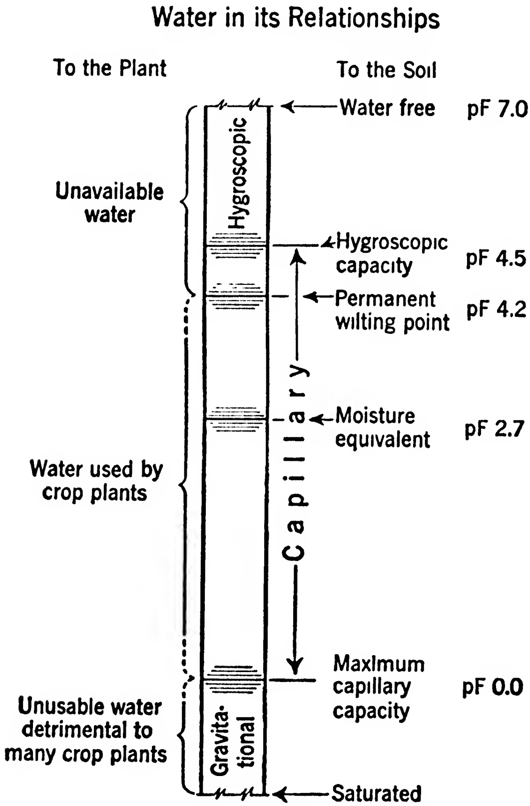

FIG. 44. Relationships of water to soils and crops.

column of water 10 centimeters high is exactly the same as the upward tension and balances the pull of gravity. This force is represented as pF 1.0. Similarly, higher up, a force equivalent to

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of the surface film of water. At pF 2.0 the tension is ten times as great as at pF 1.0 and so on to 1,000,000 times as great pull at pF 7.0 as at pF1.0. pF 3.0 corresponds closely to an upward pull or tension force or a negative pressure approximately equivalent in magnitude to the pressure of the atmosphere or about 15 pounds (14.7) to the square inch at sea level. Then pF 4.0 corresponds to 10 atmospheres pressure, pF 5.0 to 100, and pF 7.0 to 10,000 times the pressure of the atmosphere at sea level. These higher pF's represent very great forces and mean that the water in that zone is very tightly held by the soil.

the weight of 100 centimeters of water is represented by pF 2.0 and so on upward: 1,000 centimeters of water, by pF 3.0; 10,000 centimeters by pF 4.0; 100,000 by pF 5.0; 10,000,000 centimeters of water by pF 7.0. The expression pF is less cumbersome than these large numbers of centimeters of water. The water in the zone from around pF 2.7 to pF 3.8 is that most used by crop plants and is called the *optimum* water content of soils (Fig. 44). At pF 4.2 plants cannot obtain enough water from soils and wilt permanently and later die. This is known as the *permanent wilting* point. It should be understood that silt loams and clayey soils contain much larger percentages of water at any given pF, such as 4.2, the permanent wilting point, than do sandy soils. The tension, however, at pF 4.2 is the same in all soils, and that is an advantage of the pF concept of soil moisture. This moisture is moved by surface tension and is called *capillary* water. It is represented by pF 0.0 to pF 4.5. Water that is held with a force greater than pF 4.5 or about 31 atmospheres is called *hygroscopic* moisture. This water is unavailable for plant growth because plants cannot take it from soils. It is the capillary water that plants use in growth.

Holding Water in Soils. The organic-matter content, the temperature, and the texture and structure of soils influence their power to hold capillary water.

Organic matter helps soils to hold increased quantities of capillary water. Partly decayed organic matter may hold several times its own weight of water. In sands and sandy loams, bits of organic matter enable coarse-textured soils to hold more water than without such organic matter, by bridging large open spaces.

The temperature of the soil controls the temperature of the water in it. Warm water is more fluid, or flows more freely, than cool water. In other words, the *viscosity* of cold water is higher than that of warm water. For this reason soils hold more water against the pull of gravity in cool seasons than in warm ones. Even coarse soils may hold so much water in the cool days of late autumn as to cause heaving after repeated freezing and thawing.

Sandy and gravelly loams do not hold large quantities of capillary water, because of their large spaces between the grains of soil. Compacting such soil brings the particles closer together and reduces the size of the pores so the soil is able to hold water. In medium-grained surface soils the pores may be nearly full of water, especially soon after

the free water has drained out of them. Having about half of the pore space filled with water is favorable for the growth of crops.

Clayey soils that have been compacted or those with single-grain structure have tiny pores. They hold only small quantities of water that plants can use. Bringing about granulation of heavy soils by adding organic matter increases their *porosity* and their ability to hold water that plants can use.

Capillary water moves from moist soil to drier soil in all directions — upward, downward, and horizontally. The downward movement is somewhat faster than the upward movement because gravity aids downward movement and retards upward movement of capillary water in soils. If fine capillary glass tubes are placed upright in water, the water rises in them above the surface of the surrounding water. Because the pull of surface tension is greater in small than in larger tubes, water rises higher in the tubes of small diameter. Somewhat similarly, water rises higher in medium-textured silt loams than in coarse ones or in very fine-textured soils. In the fine-textured soils the pores are so small and irregular that the movement of water in them is very slow. Swelling of colloidal clay and organic matter may reduce the rate and height of the rise of water in heavy soils because friction becomes very great in the small pores.

Although capillary rise of water in soils is easily demonstrated, the rise of this water over considerable distances probably is of little importance in crop growth. Plants, therefore, send their roots after water. Movement of water through short distances in medium-textured soils, however, is probably helpful to crops. Beyond question, lateral movement of water from irrigation furrows is of real service to crops.

Downward movement of capillary water makes possible the plowing of dry soils. In early fall, silt loams sometimes are too dry and too hard to plow. A light rain (of about ½ inch) may be entirely absorbed, yet the soil is still too hard to plow. In a few days, however, the water moves downward by capillarity with the aid of gravity and softens the soil to full plow depth. This moistening and softening of the lower part of the surface soil makes normal plowing possible, whereas previous to the rain the soil was too hard for stirring.

Between rains, soils dry out and the surface ceases to lose water. The soil is then *air-dry* or has a water content that is represented by pF 4.5. This has been called *hygroscopic* water, and pF 4.5 is known as

the *hygroscopic coefficient.* This water moves only by evaporation and condensation and it is not used by plants for growth. In the management of soils in the field we have little to do with this very tightly held water. On a percentage basis, heavy soils and mucks hold several times as much hygroscopic water as do sandy ones.

At the lower end of the scale, below pF 0, is the water that is free to be pulled down through the soil by gravity. Irrigation water in a furrow moves sidewise or laterally as well as downward. It is gravity that moves water to tile or other means of drainage. *Free* or *gravitational* water that is not quickly removed from soils is harmful to crops. This water displaces air that is needed by crops, and some plant foods cannot be prepared in waterlogged soils. As a result, the growth of crops is checked, sensitive plants die, and yields are reduced. The farmer's problem is to remove this water before crops are damaged by it.

2. Improving Crops by Draining Land

Farmers have long recognized and appreciated the damage done to crops from too much free water in the soil.[2] Even greater harm comes from water that stands for a time on the soil surface. Many crops are killed in a few days by such excess water. As long ago as 400 B.C., it is recorded that farmers practiced artificial drainage in the Nile Valley.[3] In the time of Cato, Roman farmers used bundles of branches and stones in trenches to drain their lands. Drainage by similar means was advocated in England two centuries ago and was actually established nearly 125 years ago. Trenches from 10 to 40 feet apart were made 30 inches deep and filled to a depth of 12 inches with 3-inch stones.

Drainage is the important way to remove from the soil free water which is detrimental to crops. Improvement in crop yields usually accompanies the installation of suitable drainage (Fig. 45).

Increasing Granulation and Aeration. Granulation seldom occurs in waterlogged soils, and the resulting poor tilth interferes with

[2] The reclamation of swamplands and shallow lakes is an engineering problem rather than one of soil management. Reclamation of swamps and marshlands is fully treated in such books as "Land Drainage and Reclamation," by Q. C. Ayres and Daniels Scoates, McGraw-Hill Book Company, Inc., New York, 1939. Complete instructions for draining farm lands are given in this book and in those listed here.

[3] WIER, W. W., "Soil Science," p. 261, J. B. Lippincott Company, Philadelphia, Chicago, 1936.

drainage itself. As drainage takes place the surface soil dries out to some extent and this, in the presence of a supply of organic matter, permits granulation of heavy silt loams, clay loams, and clays. Because granules are so much larger than separate silt and clay particles, the granulated soil permits fairly free percolation of water into and through the soil. The mere removal of water by drains draws air into the soil and a free interchange of gases from the soil with the air above takes place in well-granulated soils. Aeration is important because oxygen is needed in the soil by plants and because of the necessity of getting the carbon dioxide out of the soil.

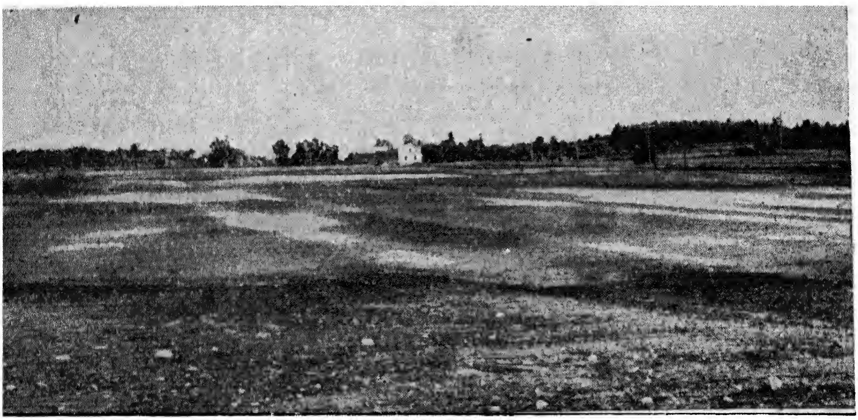


FIG. 45. Drainage is often needed in level areas. Few ordinary crops thrive on soils in this wet condition. Removal of this water is essential.

Raising Soil Temperatures. The effect of excess soil water on soil temperatures has been mentioned. Much heat is required to raise the temperature of water as compared with soil, and an enormous quantity of heat is required to evaporate water. Draining off excess water, therefore, raises the temperature of soils to a marked extent. Obviously, well-drained soils are most desired for early crops, especially vegetables, because such soils warm up early.

Aiding Helpful Soil Organisms. Many of the helpful soil organisms (Chap. 8) require oxygen from the air for their work. Soils that are too wet lack aeration and, therefore, oxygen as well. Some organisms can take oxygen for their life processes out of materials that are needed by crops. The product that is left behind not only is of no use to the crop but it may be actually harmful to some plants.

Drainage to bring oxygen within reach of beneficial life in the soil is necessary if crops are to thrive and produce satisfactory yields.

Reducing Heaving. Soils heave owing to freezing in proportion to the quantity of gravitational water below the surface. Rains may practically saturate soils in the late fall just before freezing. Because of the high viscosity of cold water, the pores are essentially full of water even in soils that usually are well drained. Upon repeated freezing and thawing of this water, much expansion takes place. If

Fig. 46. Heaving of sweet clover on imperfectly drained soil (II in Fig. 13). Unless well drained, soils may freeze while full of water in wet periods, and heaving takes place. If there is a reservoir for water as there is above an impervious layer, heaving may be severe.

this expansion is repeated often enough it lifts plants and may heave their roots out of the soil (Fig. 46). Such injury to crops may be avoided, at least in part, by thorough drainage.

Lessening Erosion. By removing water through underdrains or over the surface, the soil is in better condition to take up water when the next rain comes. A drained soil, obviously, can absorb more water than a saturated one because it is drier. Moreover, the improved granulation in the drained soil enables it to take in rainfall more rapidly than one that is not well granulated. Less water, as a result of drainage, passes off over the surface to carry away soil and valuable constituents from the surface of the land.

Making More Water Available to Crops. Drainage increases the quantity of water that is available to crops. An undrained soil may dry off enough to plant the crop, but the roots cannot penetrate below about 12 inches. A drained soil should have 24 inches of soil in good condition for the growth of crop roots. In the undrained soil the roots are confined to a 12-inch depth; in the drained soil they penetrate completely to 24 inches—a depth twice as great. In fact, the crop plants in this drained soil may well have more than twice as much total moisture to draw on for their growth as those on the undrained soil. Should dry periods come later in the season, the deeper root penetration will be of great service to the crop on the drained land. The crop in the undrained soil may suffer seriously from lack of water.

3. Selecting Ways of Draining Land

Two common methods of drainage are in general use in this country—open-furrow, or surface, drainage and underground drainage. Surface drainage was employed first but underdrains also have been used a long time.

Using Surface Drainage. Surface drainage is accomplished by means of shallow ditches or open furrows. This type of drain is used on heavy soils through which water passes slowly, especially where the slope of the land surface is slight. Hardpan soils, through which quick drainage is absent, may be surface drained. On level heavy soils and hardpan lands, plowing is done in narrow strips. A width of about 2 rods, or approximately 30 feet, is often used. Plow so as to leave the "dead furrows" parallel to each other at these distances Fig. 47). Keep the "backing" ridge and dead furrows at the same place during each successive plowing. In time, ridges are produced with a definite slope toward the open furrows. Give these furrows a slight fall in order that surface water may flow off the fields. In some places shallow surface drains are produced in other ways. These drains definitely include the diversions that are being used in the control of erosion. Diversions are so placed as to have a definite but moderate slope—one so slight that the water being removed does not cause gully formation.

Dead-furrow drains are in use on nearly level, clayey, marine and lake-laid soils in New York, on marine soils in England, on hardpan soils in southern Illinois, and to some extent in other areas. There is a

limit to the usefulness of these open drains. They can remove only the water that is *on* the surface; water *in* the surface and subsurface soil is little affected by this type of drain.

Surface drains with enough slope, however, do have one advantage over underdrains; they can remove large quantities of surface water quickly. The deeper surface drains that cannot be crossed with farm machines interfere markedly with operations and, therefore, often increase costs of production. In spite of some increases in cost, surplus water must be removed quickly from farm lands. Dynamite is being used to make medium-sized open drains.

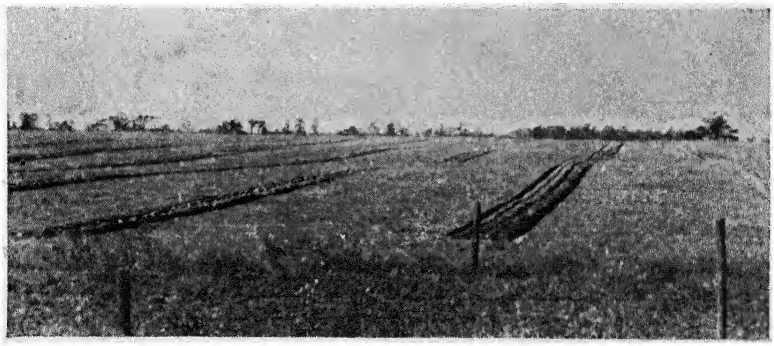


FIG. 47. Plowing in narrow "lands" effects drainage. By plowing heavy land with gentle slopes, the dead furrows serve as drainage ways to remove surface water. By opening furrows in the "draws" with a plow, a fair degree of surface drainage may be effected in this way.

Using Underground Drainage. The earliest records of underground drainage describe the use of bundles of branches, loose stones, and poles laid in the bottom of trenches. Trenches approximately 30 inches deep (with needed variations) were filled to about one-third of the space with stones 3 or 4 inches across. The water flowed through the openings between the stones, bundles of branches, or poles. Stones function indefinitely unless soil works down between them. Such drains have been found in New York that are still working after three-fourths of a century. The branches and poles, because they are wet much of the time, do not decay quickly and therefore provide satisfactory drainage over a period of years. Although these drains are less efficient than strictly open-throat types, for years they have given to crops a fair degree of relief from excess water.

Stone drains (Fig. 48) have been used in some places. One point

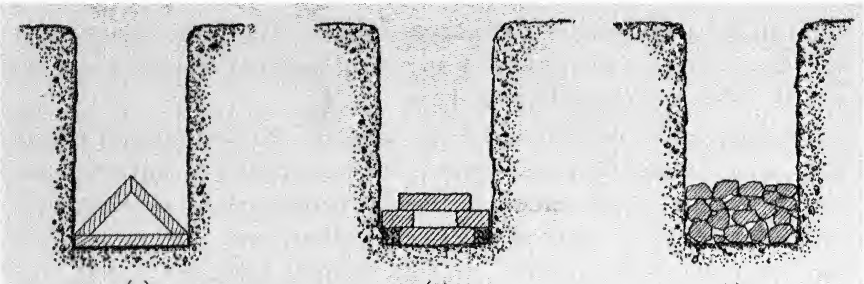


FIG. 48. Stone drains: (a) an early type, (b) a later type, and (c) cobblestone drain. Such drains, still serving after more than 75 years, have recently been found in central New York.

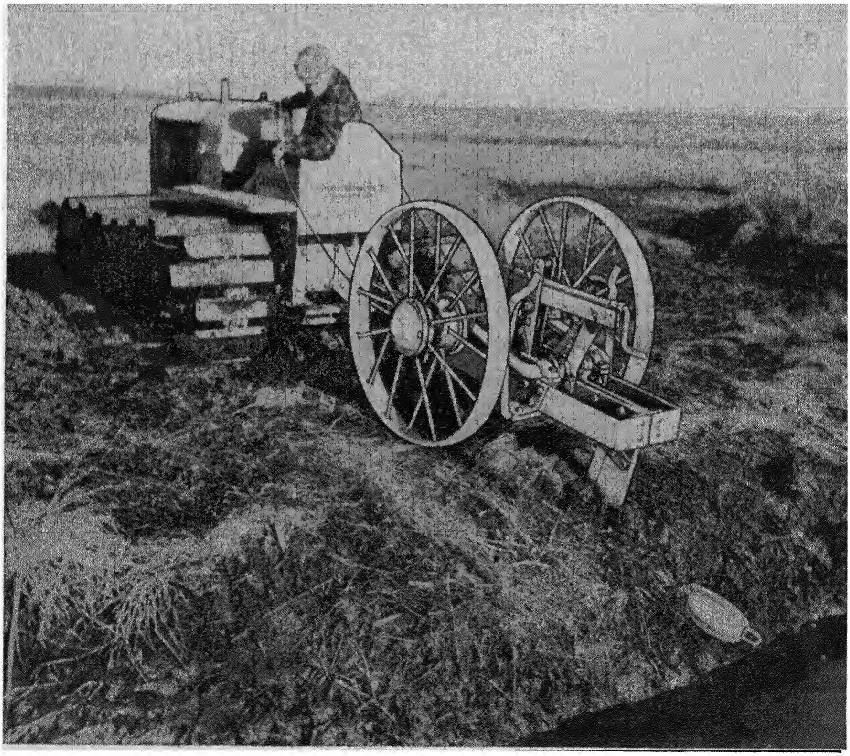


FIG. 49. Mole draining. The mole drain may be used to advantage in heavy silt loams, clay loams, and clays that are fairly free of stones. In lighter soils, there is constant danger that the opening will become clogged by the caving-in of the soil above it. (*Deere and Co.*)

for serious consideration is the quality of the stones. Some such drains have failed because the side or the cap stones have crumbled because of freezing or because poor stones were used. Soft, porous sandstones or poor shale rock fail in a few years, causing the throat to become clogged by soil from above. Thus, all the work of installation is lost. To reestablish drainage, remove the stones and relay them.

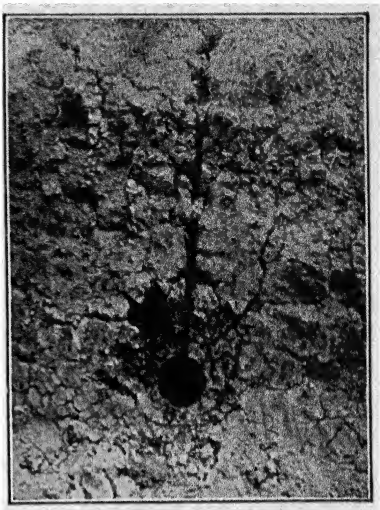


FIG. 50. The opening made by the mole-draining outfit. (*Killefer Mfg. Corp.*)

Mole drainage (Figs. 49 and 50) was installed in western Illinois during the latter part of the previous century. Although this drainage worked well for a time, it failed because some of the soils contained too little clay to make a stable arch over the opening.

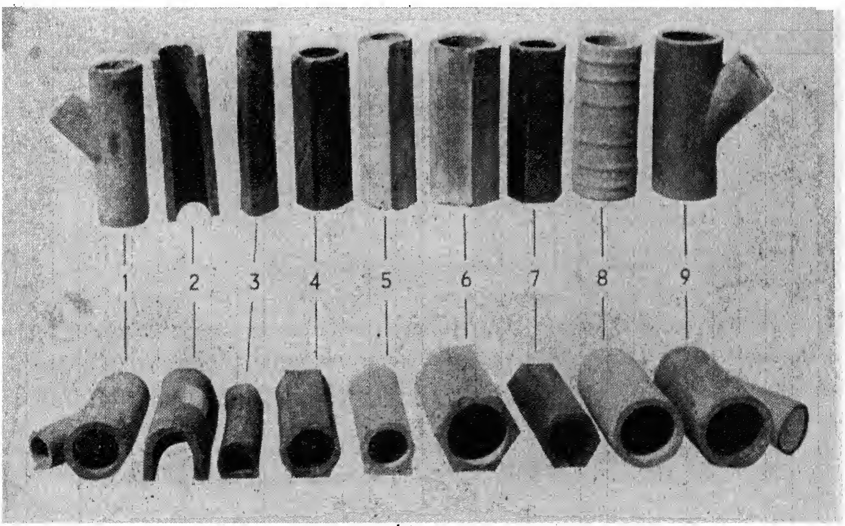


FIG. 51. Types of tile. Nos. 1 and 9 are connection tiles. No. 2 is the early tile, used in the first tiling system in the United States, installed by John Johnston near Geneva, New York, in 1835. The system is still in use. No. 3 was made later and the others are more recent developments. No. 7 is a hard-burned tile, and No. 8 is of concrete.

Interest is developing in this type of drain, and it can be used in suitable soils. In installing the mole drain, a cylinder or ball is drawn at the desired depth behind the shoe of the Killefer or similar implement.

The present-day underground drain is tile of burned clay or concrete. The first tile drain in the United States was installed by John Johnston on his farm near Geneva, New York, in 1835. The tile he used was brought from Great Britain. It was of the inverted-U-shaped type and some of it is still in use (Fig. 51).

With the development of machinery for making tile, and later for making the trenches also, the acreage of tiled land expanded rapidly. Sixty-three million acres in this country had been tile-drained up to 1930. Much additional cropland could be greatly improved by tile draining.

4. Planning and Laying Out a Drainage System

Among the recognized systems of tile drainage are the *natural*, *cutoff*, *gridiron*, and *herringbone* (Figs. 52 to 55). Most drainage systems

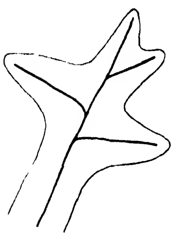


Fig. 52.

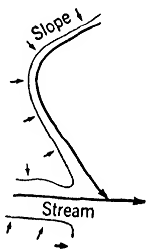


Fig. 53.

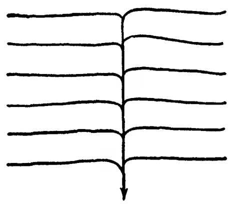


Fig. 54.

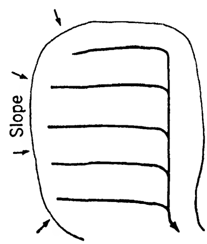


Fig. 55.

Fig. 52. Natural system of underdrainage. Small areas usually lend themselves to this system of drainage.

Fig. 53. The cutoff system. This system is often used where there is a poorly drained area at the base of a slope, particularly at the edge of gravel terraces.

Fig. 54. The herringbone system. This system is adapted for the drainage of large, comparatively level areas.

Fig. 55. The gridiron system. This system is useful on small, relatively level areas and especially on those with a cross slope toward one side of the area.

are modifications or combinations of ideal layouts. For small areas or for draining depressions or springy spots, use the natural system. In it the lines of tile follow the drainage ways, and side lines or additional ones are used as needed to drain other wet spots. Use the gridiron and herringbone systems for draining fairly level, large areas.

Unless you have watched the water running off wet lands in the spring so you know where the lines of tile should be laid, it will be necessary to make a preliminary survey with a level to determine whether or not a field can be drained. If the area can be drained, it is desirable to make an approximate contour map in order to know how much land is to be drained and, therefore, how much water must be provided for in each line of tile.

Set up the level at the outlet and determine the location and grade for the *main* tile. In exactly the same way locate the secondary mains and finally the laterals. From the acreage to be drained, the rainfall, whether the soil drains quickly or slowly, and the fall, determine the size of tile required throughout the whole drainage system. Plan the size of all mains and submains on the basis of the quantity of water to be removed and how quickly it must get away so as not to injure even the most sensitive crops. Although 3-inch laterals are used, 4-inch ones are probably more economical in the long run. The larger tile is far less likely to require cleaning. Where laterals are more than 500 feet long, a 5-inch rather than a 4-inch lateral should be used in order to carry off all of the excess water.

Use care in providing uniform slope in all lines—no high or low spots—because of the danger of clogging and the subsequent expense of digging out, cleaning, and re-laying the tile.

5. Estimating the Cost of a Drainage System

First, consider the economic benefits in the form of probable increased yields of crops because they can be planted, cultivated, and harvested at the right time, and the saving of time in doing the various jobs. Compare this with the costs of drainage. Under costs, include the length and depth of ditch required, the size and number of feet of tile necessary, the cost per foot of each size of tile, laying the tile, and backfilling the ditch. Take into consideration also the cost of construction of all outlets. Decide on drainage only if the expected benefits are likely to produce a satisfactory return on the investment.

6. Selecting Drain Tile

Two kinds of drain tile, burned clay and concrete, are in common use. A good quality of either kind is satisfactory in humid areas. Clay tile may be soft or hard burned. If well made and properly

burned either is suitable. Although soft burned tile on the surface may absorb enough water to be broken up by freezing, the danger of such injury to tile in the soil is comparatively slight. If, however, there is danger of freezing down to the depth of the tile, use hard-burned tile or lay the tile at a greater depth. Soft-burned tile is used almost exclusively in farm drainage systems. Always use a good grade of tile because poor tile will lead to trouble and additional expense.

Well-made, well-cured concrete tile also is satisfactory for draining farm lands. Such tile must be made of clean washed sand and good cement in the proportion of 1:3 or 1:4, varying somewhat with the quality of sand used. Whether to use clay tile or concrete tile depends largely on quality. A good-quality clay tile is better than a poorly made concrete tile. Similarly, a good concrete tile is safer to use than poor or incompletely burned clay tile. Of good quality, either clay or concrete tile is satisfactory for humid areas.

In highly alkali soils, salts may be present that displace the calcium in the concrete and eventually weaken it to the point of disintegration. In such an area use hard-burned tile; it is safer than concrete.

7. Ditching for Tile Drains

Spacing Tile Drains. Farmers know that coarse open soils drain more quickly than finer or more compact ones. As soils become finer, they drain more slowly with a given kind or type of granulation or arrangement of the particles. Lay drains farther apart, therefore, in quick-draining soils and closer together in slower-draining soils. If the distance between drains is the same, the soil is more completely drained sooner in quick-draining than in slow-draining soils. The distance between drains, therefore, depends on the soil and on the sensitiveness and value of crops. With sensitive, high-value crops, the grower can afford to place drains closer together than for crops of low return, such as hay and pasture grasses. The following distances are suggested: 40 feet in slow-draining soils, 60 feet in medium, and 80 to 100 feet in fairly quick-draining soils. If an effort is made to drain soils with hardpan or an impervious layer less than 2 feet below the surface, place the drains very close together. A drainage system in such soil, however, is more costly than the benefits and crop returns are likely to justify.

Determining Depth at Which to Lay Tile. Tiles are laid at depths of from 18 to 48 inches below the surface. In open soils, the distance that tile draws water or the width of the area drained depends on the depth of the tile. According to the rule of 1 foot on each side for each inch in depth, tile laid 48 inches deep will drain a strip 96 feet wide. Obviously, a drain 4 feet under the surface removes excess water more slowly than one that is 2½ or 3 feet deep. Tile functions quickly at 4 feet in coarse soils but slowly in fine-grained soils unless the latter are thoroughly granulated.

As with the spacing of tile, the sensitiveness of the crops grown also governs depth of tiling. For very sensitive, high-return crops, lay drains shallower and closer together than for low-return crops. The probable return from the land governs practicable expenditures for tiling. Underdrainage is seldom successful in hardpan or impervious subsoils. If for some very special purpose hardpan soil is tile drained, do not backfill with the original impervious subsoil. It will form a complete seal over the tile and prevent water from getting into it. As a result, the tile then can remove little water from the drained area. Backfill the ditch in such cases with cinders, gravel, or open surface soil.

Deciding on the Grade to Give Tile. Land can be drained by laying tile perfectly level but the flow is very slow. Removal of water is likely to be so slow that crops will not be properly benefited. Provide a minimum fall of 1/10 foot in 100 feet. This is the least grade that is feasible; a fall of 3/10 or 4/10 is far better and is much more easily installed. Moreover, these grades carry off water much faster than a 1/10-foot fall because increased slope greatly increases the capacity of tile. Increased fall is desirable where a lateral joins a main or submain and where a submain enters a main. Giving the last 1-foot section of a lateral or submain a fall equal to its diameter helps to speed the water in the main and to keep the main clear of sediment at that point.

Digging the Ditch. Ditches for tile drains may be dug by hand with a pick and shovel, by hand with the help of a team and plow, by horse- or mule-drawn ditchers, and by power ditchers (Fig. 56). Hand dig for draining seepy spots, or small or stony areas where only a short ditch is involved. For areas of considerable size, use power ditchers if possible because of greater speed and lower net cost. Use great care in following the grade line laid out.

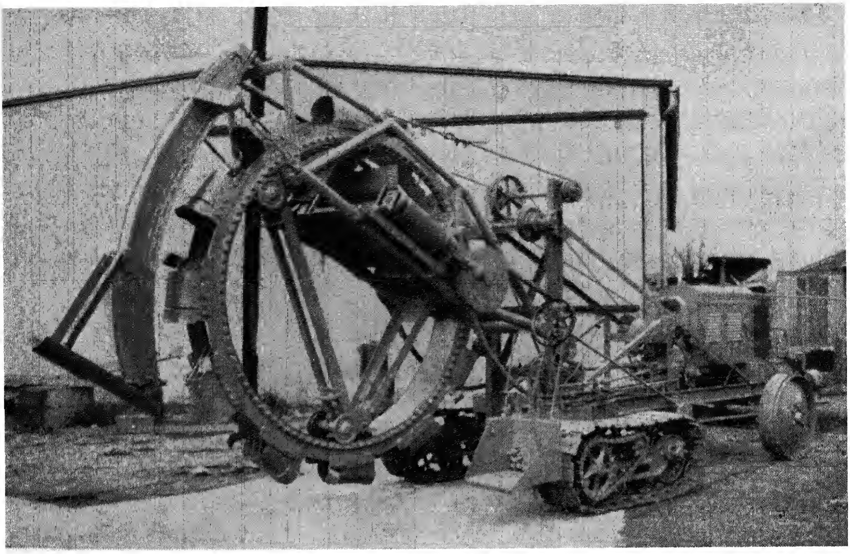


FIG. 56. The Buckeye ditcher. The Buckeye ditcher has long been popular for medium to large drainage projects. The work is quickly and inexpensively done with a machine of this kind. (*Buckeye Ditcher Co.*)

8. Laying Drain Tile

After the ditch is dug, smooth the bottom. Lay small tile with a tile hook. Such a hook can be purchased at hardware stores or it can be homemade. Take a suitable length of ½-inch pipe and place an ell on one end. Screw about a foot of pipe into the ell, making a hook at right angles to the handle. With such a hook place the tile in the trench. Usually a little care is required to lay the tiles so that the openings between them are not so large that soil can enter and clog the line.

Laying Tile in Sands. In fine sandy soils, particularly quicksands, exercise special care. Place straw, gravel, or burlap around the tile joints to exclude the fine sand so as to prevent it from clogging the lines and making the tile useless. If the tile becomes clogged, dig it out, clean it, and re-lay it. This is the only way to restore a line of tile to usefulness.

Filling the Ditch. After tile is laid, the first step is "blinding" it. Carefully throw small quantities of soil without clods or stones on both sides of the tiles to hold them in place. After the blinding has been carefully done, fill the ditch by the easiest method. Backfill

short, small ditches by hand. For long, large ditches, use machinery. Use a slip scraper for a small job; for a large job use a blade road grader, a light terracer, or a bulldozer. All are suitable implements for quickly filling tile-drain ditches.

Protecting Tile Outlets. Outlets require protection. If the larger rodents or animals of similar size enter tile, they cannot turn to

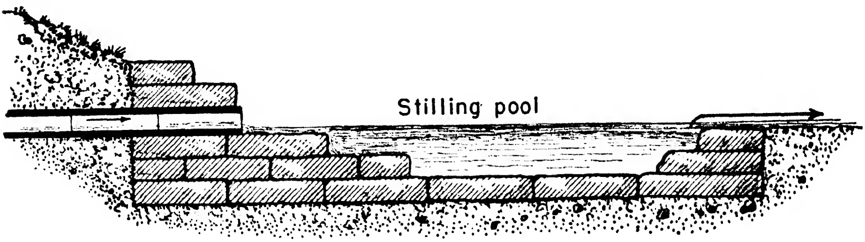


FIG. 57. Outlet protection. Many tiling systems have failed because their outlets were not protected against such hazards as erosion and the trampling of livestock. Livestock prefer the cool water from the tile to that of shallow streams or ponds. Flat stones, flattish boulders, or concrete may be used for this purpose.

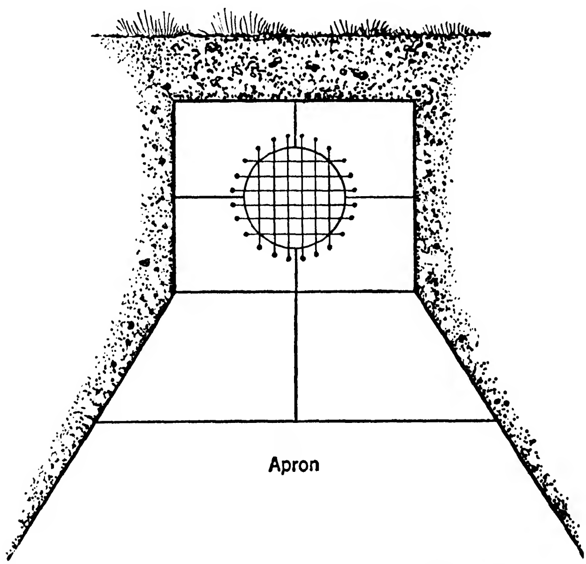


FIG. 58. Protecting outlets against rodents. Iron rods about 3/8 inch in diameter may be embedded in concrete across the end of the tile. The rods are placed both horizontally and vertically, forming squares from about an inch across. This lattice prevents large rodents, which might clog the tile, from entering it. Protection of the rods against rusting is desirable. Heavy hardware cloth may be similarly used.

get out again (Figs. 57 and 58). The drain, therefore, is likely to be clogged and to require digging out in order to clear it. Use small iron rods placed an inch or two apart, or coarse hardware cloth, for keeping animals out.

Protection of the outlet against erosion is equally necessary. Unless protected, the end tile is eventually undercut and falls out of line, and soon a gully works its way up the drain. In cropped fields, the gully and the water so released interfere with the work of production and harvesting of crops. In pastures, the livestock tramp unprotected tiles out of line and do serious damage to a drainage system. Provide outlets with an apron of concrete, flat stones, or a deep layer of other stones with grasses in close contact. This helps to hold the end tiles in place and keep the drain in good working order.

9. Keeping a Drainage System in Operation

Drainage systems require some attention to keep them working right. Make an occasional inspection to see if there are any wet places along the length of a drain. Wet places indicate a clogged place in the tile. If near the end they may be cleaned. Elsewhere, however, the tile must be dug out, cleaned, and laid again. If willows are within 100 to 150 feet, clogging by their roots may be expected. Destroy such willows, and other water-loving shrubs and trees. If necessary, dig out, remove the roots, and re-lay the tile.

Often holes appear on the surface above the tile. Usually, in such instances, a tile is broken and it must be dug out and replaced. It is far cheaper to inspect drains occasionally and make needed repairs promptly than to neglect them. One broken tile may lead to clogging and may require digging out and cleaning a considerable length of drain.

Outlets also require occasional attention to make certain that the end remains screened. Protection against erosion at the outlet must be maintained. If any part of a drain line is disturbed by livestock or by frost action, restoration is needed to protect the usefulness of the entire drainage system.

10. Reducing Loss of Water from Soils

Water is lost from soils in a number of ways, some of which are unavoidable, sometimes even desirable; others are avoidable and most undesirable. Loss of water by percolation is largely beyond control

and its entrance into the subsoil is highly desirable. Some of this water remains within the reach of the roots of crops, and that which goes too deeply for crops replenishes the supply of ground water for wells, springs, and streams. It is generally essential that rain water percolate into the soil. If it does not, it runs off, or the surface is waterlogged, a condition wholly unfavorable for fruits and most farm and garden crops.

The extent of percolation is of interest to the farmer. This phase of water control was studied at the Cornell University Agricultural Experiment Station over a period of years. One of the soils used was Dunkirk silty clay loam, a soil that was formed in glacial-lake water and has satisfactory, although somewhat slow, drainage. Two-thirds of the rainfall passed through the top 4 feet of bare soil, but only one-half of the rainfall percolated through the same depth when the surface soil was cropped each year. Cropping, therefore, is a means of reducing losses by percolation.

Cropping also markedly reduced the loss of plant food from this soil. The loss of nitrogen was but little more than one-tenth as great from the cropped as from the bare soil; that of calcium was about three-fifths as great from the cropped soil. Distinct but smaller savings of potash and magnesia than of nitrogen and lime occurred from the cropped in comparison with the bare soil. Similar studies were made on Volusia silt loam, an acid soil that was formed from the weathering of shale with a small addition of foreign material by glaciation. Compared with the bare soil, the cropped one lost less plant food of all kinds, but the saving by cropping was less than in the Dunkirk silty clay loam. Similar losses of plant food may be expected in the drainage water from tile or in the water of shallow springs.

Runoff losses are generally undesirable and largely avoidable, except when excessive rains fall on soil that is frozen or already saturated. Much can be done to control losses of water by runoff, and this is an important phase of the control of soil erosion (Chap. 5).

Water is lost from soils by evaporation. With certain crops, mulches of organic matter are a feasible means of reducing this loss. Mulches of soil are not very effective. In dry periods, decreasing the loss from evaporation is desirable but not easy to do. As already pointed out, plants use enormous quantities of water in their growth. This water is evaporated from the leaves and stems of

plants. Although such water is absolutely essential for the growth of plants, it may, nevertheless, be regarded as a loss from the soil's supply of water. Fertilization reduces the quantity of water required for the production of a unit of crop, but because fertilization increases yields it probably has little effect on the total quantity of water used by crops.

11. Determining the Relationship of Soil Water to Plants

The relation of water to plants is of importance equal to its relation to the soil. *Gravitational* water (pF 0) is not useful to most crop plants; it is harmful and, therefore, must be removed. Certain water-loving plants, called *hydrophytes*, thrive in the presence of gravitational water. The *outer capillary* water (around pF 1), although used by some crops, does not allow sufficient aeration for others. Similarly, the *inner capillary* water (about pF 4) is so tightly held by the soil that many plants are unable to obtain enough water for good growth. It is the middle or *optimum* zone of capillary water in which most crops make their best growth. Plants wilt permanently before all of the inner capillary water has evaporated from soils. The moisture content of the soil at the time plants wilt permanently is called the permanent wilting percentage. Unless rain falls or the soil is irrigated before permanent wilting occurs, the crop dies. Loss of water from evaporation, however, continues from both soil and plants.

Determining Water Needs of Crops. Crops require large quantities of water for their growth. The weight of water actually used by plants in producing 1 pound of dry matter is called the *unit-water requirement.* Water lost by runoff or by evaporation from the soil is not included in the water requirement of crops. Plants vary considerably in their use of water. The term *total water requirement* includes the water actually used in the production of a crop on a unit area. Unit-water requirement varies with soil conditions, the climate, and the crop.

Soil Texture. Soil texture appears to have little effect on the unit-water requirement of crop plants. They require about the same quantity of water for 1 pound of dry matter whether grown on sandy loams or clay loams. Very dry or very wet soils, however, increase the unit-water requirement. A crop grown on a poor soil—one of

low productivity—uses more water than one that is grown on a productive soil. The use of fertilizer on a poor soil increases the efficiency of soil water; that is, the unit-water requirement is lower on the fertilized area.

Climatic Conditions. Leaf and air temperatures and the relative humidity of the air affect the quantity of water used by plants. High temperatures increase evaporation and, therefore, the quantity of water actually used in their growth. In dry areas or those of low humidity, evaporation from a free-water surface is high; it is high also from plants. Warm dry winds greatly increase evaporation from plants. Unit-water requirement is also closely related to humidity. Where relative humidity is low, unit-water requirement is higher than where the humidity is higher. Peas in Utah and Colorado used twice as much water per unit of dry product as in Wisconsin. In contrast, corn required little more water in the drier areas than in a humid one.

Variation in Crop Requirements. Crops vary in their economy in the use of water. Briggs and Shantz studied several crops at Akron, Colorado. Alfalfa used 1,068 pounds of water for 1 pound of dry matter, the highest unit-water requirement. All the other legumes were high in their water requirements: peas 800 pounds, red clover 789, sweet clover 709, and beans 728 pounds. Among the grains rye was high—724 pounds, followed by oats 614, barley 539, and wheat 507 pounds. Corn, sorghum, and millet were rather economical in their use of water: 369, 306, and 275 pounds of water respectively for 1 pound of dry matter. Potatoes used 488 pounds and sugar beets 377—both fairly economical.

All of these studies were made in a dry climate, and are higher than would be expected in a humid area. A 3-ton crop of alfalfa under irrigation requires nearly 30 inches of water. According to King, corn in Wisconsin used 350 pounds of water to produce 1 pound of dry matter. An 80-bushel corn crop, therefore, would use about 13 inches of water. Much less than 3 inches of available water a month is likely to result in a reduction in corn yields. These total water requirements per acre indicate the need for conserving water for crops during the growing period, and, indeed, indicate the necessity for adding water during periods of low rainfall, even in humid areas.

12. Dry Farming

The growing of crops in areas of low rainfall without irrigation is called *dry farming*. The moisture that falls is conserved, and selected strains of drought-enduring crops are grown. Dry farming is practiced where the average annual rainfall is from 10 to 20 inches. Only soils that absorb water and hold it against drainage are suitable for dry farming.

Distribution of rainfall is important. It is best for most of the year's rain to come in the growing season. If most of it comes in fall and winter, winter wheat is likely to be an important crop because it can grow and mature before the soil becomes too dry in the spring. By cultivating, or fallowing (page 104), part of the rainfall is stored for use by crops the following year.

Location with respect to latitude and altitude require consideration. Ten inches of water well distributed in the cool weather of the Dakotas may produce a crop under favorable conditions. Because of the high evaporation in the high temperatures of Texas, 20 inches of water equally well distributed may be less effective in producing crops. Moderately low temperatures and moderate to low evaporation are favorable to the production of crops in dry-farming areas.

Selecting the Soils. Deep, absorptive soil is needed for dry farming (Fig. 59), although the precise depth needed cannot be stated. It is true, however, that 4 feet or more of good soil is preferred to shallower depths. Bedrock near the surface, a hardpan layer, heavy clay subsoil, high water table, or gravelly subsoil are objectionable for dry farming because they restrict the development of crop roots. Deep soil is needed because many crops that are shallow rooted in humid areas root deeply under favorable soil conditions in dry-farming regions. In the latter condition the roots go down after water, but in humid areas they get sufficient water by producing a shallow root system in the surface soil.

Medium- to heavy-textured soils are best because they retain water much better than sandy or gravelly soils. In the coarse soils, water may percolate beyond the reach of roots and be actually lost to crops. Of course, if the rain falls in the growing period coarse soils are more productive than if it falls in winter. Winter rainfall is lost before a growing crop can absorb it. Clays and clay loams are often chosen because they hold water well (Fig. 60).

Soils that contain much of soluble salts, commonly called *alkali*, are not suitable for dry farming. Owing to the fact that the alkali cannot be washed out, it may hinder greatly the growth of crops (see Chap. 7).

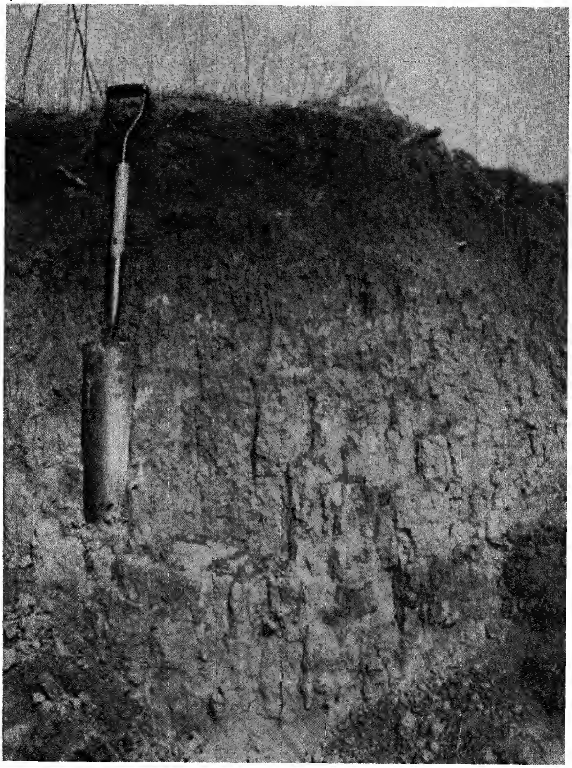


FIG. 59. Nebraska soil suitable for dry farming. This uniformly textured silt loam is ideal for dry farming. It holds water well and delivers it to the crop. There must not be any layers of sand or gravel in the upper 4 to 6 feet of soils for successful dry farming. (*U.S. Soil Conservation Service.*)

Choosing Drought-enduring Crops. Crops that can adjust themselves to dry-farming conditions—soil, temperature, evaporation, rainfall—produce the best yields. There is no assurance that high-yielding varieties or strains from humid areas will produce equally well in dry-farming areas. Many failures in dry farming result from seeding humid-region varieties under dry-farming circumstances. Choose adapted varieties of crops that endure droughty conditions. Wheat is widely grown, but only adapted varieties and strains can be

FIG. 60. The damming lister. The damming lister is used to make depressions for holding water on sloping dry-farming lands. (*Minneapolis-Moline Power Implement Co.*)

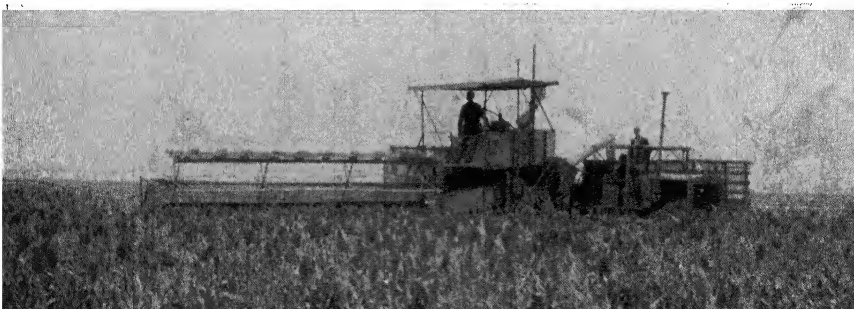


FIG. 61. Combining grain sorghum. Here Cody sorghum is being harvested with a 20-foot combine. This type of extensive farming can be carried on advantageously in the Great Plains. Wheat is handled in much the same way. (*A. F. Swanson, U.S. Department of Agriculture and Kansas Agricultural Experiment Station.*)

expected to prove successful. Durum wheat from Russia has been a good producer in the dry areas for many years. Kafir, dwarf milo maize, rye, barley, corn, potatoes, cotton, beans, peas, and grasses are grown in the dry-farming areas of the western United States (Fig. 61). These crops are most widely grown although others also may prove profitable. Agronomists are constantly seeking suitable new or

improved varieties and strains. The most promising ones developed are finally recommended to farmers. Varieties or strains have been found that become partly dormant and in that condition require little water, and varieties that mature in less than the usual frost-free period are looked upon with favor. The rates of seeding practiced in humid areas are too high for dry-farming areas. Relatively, very light seeding gives best yields in dry-farming regions.

Growing one crop continuously is no better practice in dry-farming than in humid areas. Alternating wheat with summer fallow or rotating crops gives better results. Wheat is often alternated with corn. In some places wheat is grown 3 years and the land left fallow the fourth year. Pasturing certain fields a few years and making full use of farm manure improves yields, especially in the years of more favorable rainfall. Trials are constantly being conducted to find better cropping systems in various dry-farming areas.

Tilling the Soil in Dry Farming. There is considerable danger that soil may be lost by wind erosion in dry-farming areas. In periods of low rainfall and high evaporation, the soil becomes very dry and is subject to severe blowing. In 1934 the rainfall was only one-third of normal and dust storms were unusually severe. Not only soils but crops were badly damaged. The erodibility of soils by wind is governed by their texture and structure. Sands, because of their single-grain structure are easily moved. In clay soils tiny aggregates may form that, because of their high porosity, are lighter than sand grains and blow about readily. Any soil in a finely pulverized condition in dry areas is subject to blowing.

Such implements as the disk and peg-tooth harrow that pulverize the soil are usually not desirable for use in dry-farming regions. It is better to use implements that produce a rough surface with many small clods. The clods should not be large, yet they should be of sufficient size to prevent blowing. The lister, a double plow that opens a furrow by throwing the soil both ways, is used to make ridges at right angles to the prevailing winds. This reduces blowing, but when furrows are filled with soil new furrows are made. If the lister is used to prepare the seedbed for maize, place the seed in the bottom of the furrow. In cultivating the crop, gradually fill in the furrows. After the crop has made a foot or two of growth the crop holds the the soil by checking wind movement.

Fields are often divided into strips about 150 feet wide, at right

angles to the prevailing winds. Half of the strips are left bare, and the alternate ones planted to crops. These crops act as windbreaks and hold the soil against blowing. At the same time that they check wind velocity they reduce the loss of water. Saving moisture helps to check blowing and benefits the crop.

The land that is kept free of vegetation is called summer *fallow* or is said to be "summer fallowed." In places the stubble is disked in summer and seeded the following fall or the next spring. Although weeds are sometimes allowed to grow, most authorities hold that successful fallow is clean and weedless.

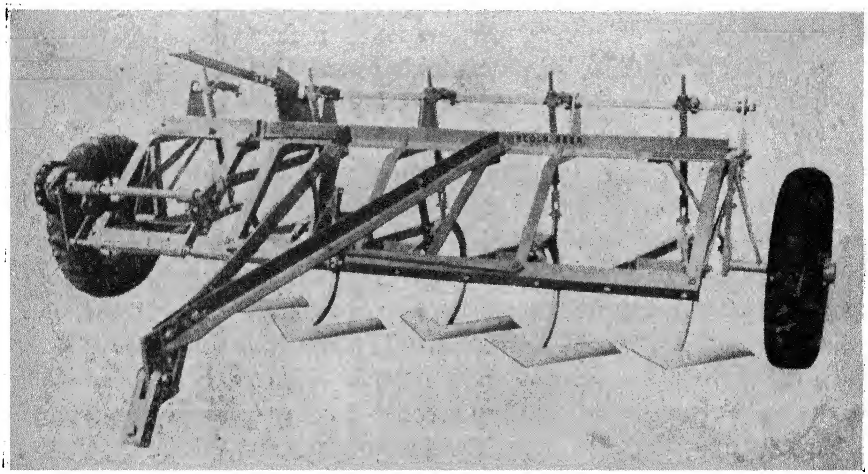


FIG. 62. A duckfoot cultivator for subsurface tillage. Subsurface tillage for leaving stubble and combined straw on the surface can be done in light- and medium-textured soils with this type of implement. (*U.S. Soil Conservation Service.*)

A certain acreage is kept idle in summer fallow each year where the growing-season rainfall is low, because good yields usually follow fallowing. Cropping all the land each year is likely to lead to complete crop failure in the drier years. Fallowing, then, is insurance against total crop failure. Although moisture is lost from the soil, fallowing holds some of the rain and snow water for use by the next year's crop. Controlling the weeds by cultivating after each heavy rain holds from one-third to one-half of the rainfall. A 10-inch rainfall may provide from 13 to 15 inches for the crop in alternate years. Of course but one crop is harvested in 2 years. Ten inches of water, except in areas of unusually low evaporation, is considered the lower

limit for successful dry farming. Accumulating water for 3 years for use by the crop in one season is seldom a success.

With annual rainfall of about 18 inches, summer fallow is used less to accumulate water than to accumulate readily available plant food in the soil. Areas of high evaporation, however, would need to conserve water. Tillage early in the season for weed control helps to make plant food ready for the next crop. In such situations, using fertilizer instead of fallowing may be more profitable. Practice only

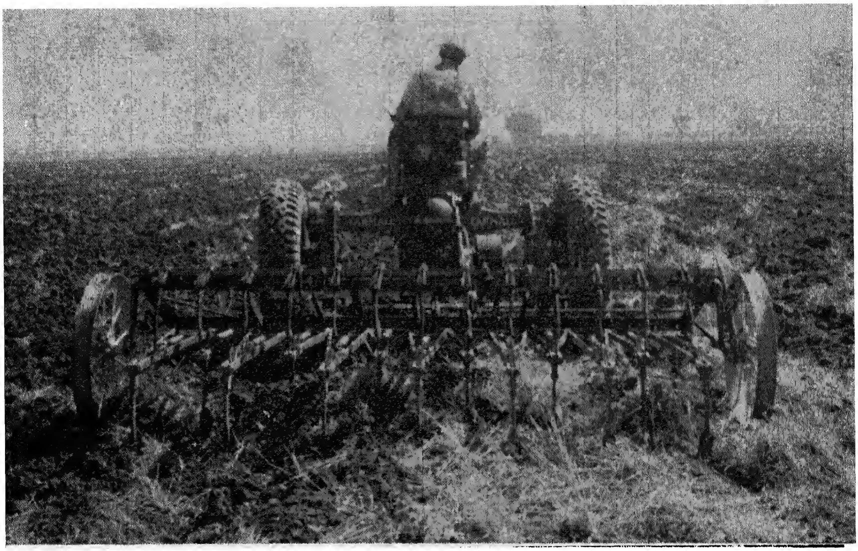


FIG. 63. A field cultivator leaving trash on the surface. This field had been plowed but was very cloddy. This sturdy shovel cultivator is bringing trash back to the surface for its protection against erosion by both wind and water. (*U.S. Soil Conservation Service.*)

those tillage methods that have proved desirable in your particular area. More tillage than necessary increases the cost of producing crops and pulverizes the soil too finely. Wasteful blowing may follow.

Tillage varies with the soil, crop, and climate. In the northwest states, the stubble is left to hold snow which, upon thawing, increases the moisture supply in the soil (Figs. 62 and 63). In contrast, farmers in the southwest states stir the soil soon after harvest. Part of the stubble is left exposed and the soil is coarsely granular. This stirring helps to control weeds, checks wind erosion, and puts the soil into condition to absorb winter and spring rains.

It is sometimes advisable to give corn an occasional shallow cultivation to control weeds. Cultivation mainly to produce a mulch, however, is not looked upon as good practice. As in humid areas, on medium-textured soils the principal value of cultivation is the control of weeds. Avoid pulverizing the soil. This may encourage blowing, and water enters soils with small lumps or clods more readily than it does soil with a finely pulverized surface.

Time of plowing has been studied, but because of varied conditions in dry-farming areas no one time is best in all of them. Fall plowing is done in some areas and spring plowing in others. The depth of plowing is from about 5 inches in sandy soils to 8 inches in clay loams. Because of the doubt concerning its value, less subsoiling is done than formerly. Yet, some authorities advise trials with the subsoiler in an experimental way.

Using Fertilizer—A Doubtful Practice. Some workers question the use of fertilizer nitrogen. It may so increase early growth of the crop that the soil moisture available may not be sufficient to mature the crop. Experimental work is needed in many areas to determine the best amount of each plant food to use. Cost of fertilizer and its application require consideration in deciding whether or not fertilization is profitable. Although some soils may be low in plant food, the supply of moisture usually limits crop yields in dry farming.

13. Irrigating Crops in Regions of Low Rainfall

Irrigation, especially of high-return crops, is practiced in semiarid regions because the rainfall is not sufficient even for dry farming. Much of the irrigated land in the United States lies west of the hundredth meridian, or about the eastern edge of the 10- to 15-inch rainfall area. This runs from eastern North Dakota to western Texas. About 20 million acres are now being irrigated, and an equal area is nonproductive because of lack of water. More land, however, is being brought under irrigation from time to time. Representative of this recent expansion in irrigated acreage is that from the Grand Coulee dam and that in the central valleys in California.

Planning for Irrigation. Wherever rainfall is too low or too uncertainly distributed for successful dry farming, irrigation deserves consideration if water is available at reasonable cost. Because water in dry areas is often charged with a high percentage of soluble salts, examination of irrigation water is the first step in planning for irrigat-

ing lands. Some salts are more toxic to crops and detrimental to soils than others. Not only the total salt content but the particular salts that are present require determination. Examine the soil also, because dry soils have not been leached of soluble materials. Sodium carbonate and boron compounds are two of the most harmful salts. Relieving the condition produced by soluble salts is covered in Chap. 7.

In planning for irrigation consider the quantity of water required to produce crops. Be certain that the supply will be sufficient for all needs. According to Widtsoe, in Utah, potatoes, wheat, sugar beets, corn, oats, and alfalfa (4.7 tons an acre) used from 26 to 40 or more inches of water. All the crops produced large yields. The quantity of water needed by crops varies with soil, temperature, and wind movement. In very open soils, water is lost by drainage into the subsoil. More water is lost by evaporation from plant and soil surfaces at high temperatures and high wind velocities than at lower temperatures and lower wind velocities. In addition, crops vary; clover and alfalfa require more water than do the cereal grains and many other crops.

Preparing a Field for Irrigation. In order to irrigate crops by the furrow method, grade the land to the slope desired. Provide sufficient fall for the water to flow from the supply ditch across the field. Level the surface, cut down high spots, and fill low places. Either high or low spots make proper distribution of water impossible. For flooding, border dams must be built to hold water. Less work may be required for irrigating by the sprinkling method on rough land. Establish the proper slopes or levels, depending on the method of applying water, before beginning to irrigate crops.

Using Different Methods of Irrigating. Whatever method of irrigation is used, distribute the water evenly and put on enough to moisten the soil to the depth to which crop roots grow. If too little water is used, plants soon wilt. Examine the soil after 2 or 3 days to learn whether the whole root zone is moist. To put on water enough to wet the soil much beyond crop roots is wasteful. Too much water carries available plant food down out of reach of the roots, and plant food is thus wasted. Water costs money and other lands need water; use it wisely (Fig. 64). Alkali soils, however, may well be heavily watered at regular periods to flush the harmful salts down and out of the soil beyond the zone of crop roots.

Furrowing. A common method of irrigating orchards, especially on hillsides, is by means of furrows that follow the contour. Hillsides are often planted to orchards because there is less danger of frost injury than in level places. Furrow irrigation of orchards has grown in favor in recent years. The irrigation water is brought to the furrows through ditches, flumes, or pipes (Figs. 65 and 66). These have

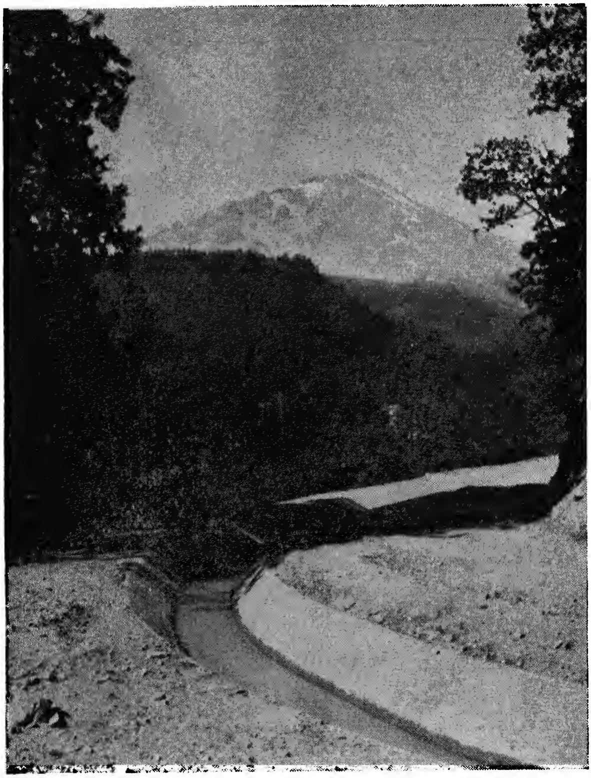


FIG. 64. Canal delivering water for irrigation. Some canals are entirely in the soil; others, like this one, are lined with concrete to prevent leakage. Water is carried from streams or reservoirs to the areas to be watered. (*U.S. Forest Service.*)

openings that can be closed to control the quantity of water supplied to the furrows. Alfalfa, vegetables, and other row crops also may be irrigated by the furrow method.

The kind of soil and the percentage of slope control the grades in the rows of trees. Make the furrows parallel to the rows of trees if they are on the contour. Furrows must have fall enough for the water to flow, but not enough for much washing to take place. With

shallow soils and steep grades in the rows, fewer furrows are needed than in deep soils. In mature orchards on deep valley soils, six or more furrows for each row of trees are not uncommon. Do not make the furrows too long. With long furrows in open soils, a small head of water penetrates deeply near the head of furrows and leaches plant food into the deep subsoil. The trees at the lower end of furrows, however, do not get enough water. On sandy soils irrigation is done

FIG. 65. Irrigating siphons. Siphons of rubber (tubing), plastics, or other material are used for transferring water from a submain ditch into the furrows between rows of crops. This method is more efficient than some of the older ones. Because only a limited number of rows can be irrigated with the water available at one time, no large supply of siphons is required. The water has been shut off, and the siphons may be moved to other areas. (*E. V. Staker.*)

at shorter intervals than on clayey ones because the clays hold water better. Shallow-rooted crops require more frequent irrigations than do deep-rooted ones.

Vegetables in irrigated areas are often planted in beds, usually about 20 inches wide, and the beds are about the same distance apart. Put the water on in the furrows between the beds and not on the beds themselves; otherwise a crust forms on surface-watered heavy soils through which the plants of small-seeded vegetables cannot come up. This is the reason for using beds and irrigating between them. Make the beds in fairly dry soils with the lister or moldboard plow,

and smooth by dragging. Plant the crops near the edges of the beds, which are subirrigated from the furrows. This method of irrigation, particularly on adobe and other heavy soils, keeps them in good physical condition.

Wells may supply water for furrow irrigation, as in fact they do in the San Luis Valley in Colorado, in the Santa Clara and other areas in California, and in various regions where other supplies of water are not available. Irrigation water from streams is more commonly used, but when this supply is inadequate or not available, water from

FIG. 66. Furrow irrigation in Colorado. Peas are being irrigated in furrows. At the right the water is well through the rows. At the left the man is letting the water into the furrows. Only a limited number of rows can be irrigated at one time with the supply of water available. When the rows at the right have received enough water, it is shut off and turned on to the other rows. (*O. P. Pennock, Colorado.*)

wells is employed. Wells are often 16 or 18 inches in diameter and are cased to depths of from 30 to 100 feet. The water is pumped to the surface, where it is run into irrigation ditches. From them the water is used to irrigate potatoes, alfalfa, grain, or other crops by furrowing or flooding. If the water is used advantageously, one good well may supply irrigation water for about 160 acres of cropland.

Flooding. A system of flooding is commonly used if there is a plentiful supply of water and much land is to be irrigated (Fig. 67). Water is diverted from large irrigation ditches to nearly level land. Leveling is best done when the soil is dry, otherwise it may be puddled. In that condition water does not penetrate the soil well and the growth

of deep-rooted crops is hindered. The water is controlled by basin, contour, border, or strip methods. The basins used in orchards and vineyards are made so the water flows from one to that next below it. The contour method is used on irregularly sloping land by building contour levees with a vertical interval of about 25 inches. Other contour levees are made so as to enclose narrow basins. The percentage of slope, the water available, and the crop to be grown govern the distance between levees.

FIG. 67. Irrigation by flooding in California. Apricots are being irrigated by the flooding method. After one area has been watered sufficiently, the water is turned off and passed down the ditch to other areas. (*F. J. Viehmeyer, California Agricultural Experiment Station.*)

The levees can be made with different tillage implements. For alfalfa, make the height and width suitable for the use of ordinary mowers. Levees in orchards may be higher and their sides steeper than in alfalfa fields.

The border, or strip, method is much used for alfalfa because water can be put on uniformly and with little work. In using this method, level the land along a line at right angles from one levee to another and give the basin a gradual slope parallel to the levees, or checks. The dimensions of the checks depend on the soil and the water available. In sandy soils the checks are usually made 20 to 30 feet wide and about 300 feet long with a water supply of 450 gallons a minute. With

this quantity of water, the checks in clay soils may be 30 by 600 feet. Before the checks are built, study the soil and the grades of the surface of the soil along with the quantity of irrigation water available. Avoid the mistake of making checks so long that the upper part receives too much water and the lower end too little.

In locations with heavy soil that bakes and does not absorb water readily, furrows or corrugations are made about 20 inches apart.

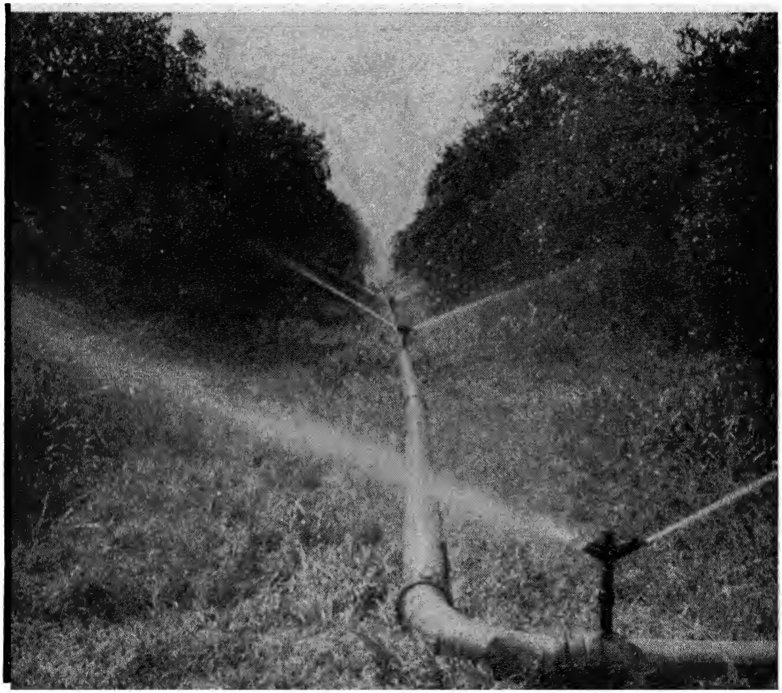


FIG. 68. Irrigation by sprinkling in Texas. This citrus grove in the Rio Grande Valley is being watered by means of this portable irrigation system. (*Champion Corporation.*)

Small streams of water are run in the furrows. Puddling and baking of the soil is thus avoided.

Sprinkling. The most common way of irrigating small areas is by sprinkling. Sprinkling systems are also used in orchards and on some vegetable and field crops (Fig. 68). Gravity or pumping supplies the necessary pressure. Correctly spacing the sprinkler heads is important. If they are too far apart some of the field is not watered enough, and if they are too close together the double-sprinkled area is too wet

or part of the field is not moistened sufficiently. In lawns, sprinklers may be installed permanently so as not to interfere with mowing the grass. In orchards and nurseries place the sprinkler heads in such locations and at such heights above the ground as not to interfere with plowing, cultivating, or other tillage operations.

Temporary or portable types that employ lightweight pipes are coming into wide use. The pipes can be quickly disconnected, moved, relaid, and locked together so that they are watertight. This method is used mainly for vegetables and sugar beets. Permanent underground and overhead piping are used, but they involve a considerable initial investment.

Subirrigating. In low places with an impervious subsoil the water table may be rather near the surface. The water comes from springs or higher lands. The crops grown are usually shallow-rooted ones and the height of the water table is controlled by ditches and pumping. The water table is controlled because wide variations in it are unfavorable for good development of the root systems of the crops. Sprinkling systems are sometimes employed on subirrigated land to make small applications of water for the benefit of the upper roots. The deeper ones are, of course, watered from below.

Subirrigation is accomplished also by laying lines of tile and running water into them. The water leaks out at the joints between the individual tiles and waters the crop from below. Some difficulty results from roots that enter and partly clog the tile. Periodic cleaning with rods and tile-cleaning brushes is required to keep them working right.

14. Irrigating Crops in Humid Areas

The long-term average rainfall of the growing season in the humid area of this country is ample for the production of good yields. Nevertheless, crops often suffer from a lack of water during periods of drought. There are few seasons in which there is not at least a short period of light or no rainfall. And in some seasons the rainfall is only two-thirds or three-fourths of normal. Droughts occur in spots every year and over large areas at longer intervals. A study of the average growing-season rainfall over long periods does not yield the desired information with respect to the adequacy of the rainfall. Instead, consider the rainfall of a number of years by 10-day periods to get the information needed. One really needs to know how often there are

10-day periods with little or no rainfall. The percentage of low-rainfall periods gives a clue to the probable need for supplemental irrigation in humid areas. It is more essential to maintain uniformly high production of food than of feed crops; attention, therefore, is given mainly to irrigating vegetable and fruit crops. Soils for vegetables and fruits are chosen because they are well-drained, early ones. Quick-draining soils cannot also be retentive ones. They are almost certain to be droughty and in particular need of supplemental water during periods of low rainfall.

Providing Irrigation Water. A source of water is the first consideration. In some places "city" water is used. On Long

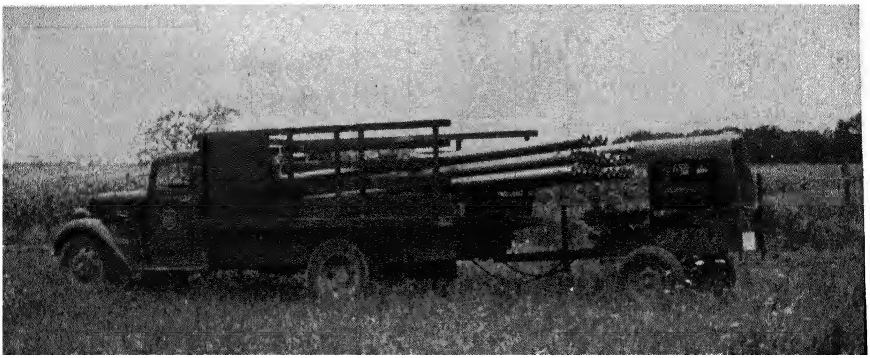


FIG. 69. Portable irrigation unit in New York. The pump, with an auto engine for power, is mounted on a trailer. The lightweight portable pipe is transported from farm to farm as shown here. (*John Lamb, Jr., Research Division, U.S. Soil Conservation Service, New York.*)

Island many large-size wells have been driven specifically for supplying water to irrigate potatoes, cauliflower, and other vegetables. The pumping is often done with Diesel engines. On many farms a low dam on a small stream or a hole dug in the bottom of the channel supplies enough water. Farm ponds in seepy spots on hillsides can serve as a source of water. "Sky" ponds that are filled directly and only by rainfall on a well-grassed watershed may supply water. In other places temporary or summer dams in streams on higher areas supply water that may be piped down to the garden or the field of vegetables (Fig. 69). Portable gas engines, electric motors near the farm buildings, or the farm tractor may be used for pumping, especially if the water comes from a source other than wells.

On moderately slow-draining yet well-drained soils, tile drainage along with irrigation is desirable; otherwise heavy rains soon after irrigation may damage crops that are easily injured by too much water in the soil for a few days.

Applying Water. The irrigation system in humid areas is usually a sprinkling system (Fig. 70). There are numerous types of sprinkler heads for use in either a permanent-pipe system or a

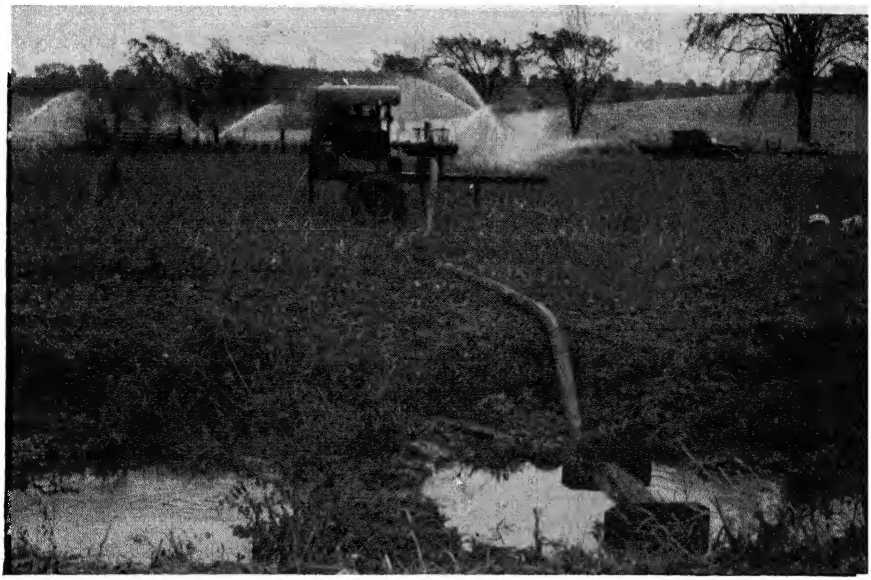


FIG. 70. Portable irrigator in action. Upon arrival at the farm the trailer is left with the pump near the source of water. The screened intake is placed in a stream or pond and the pipe laid, connected, and adjusted. The pump is started and irrigation is quickly under way. 1.6 inches of water was applied to an acre of beets in 3½ hours. The yield of cannery beets was increased from 11.4 tons on the unwatered soil to 14 tons an acre on the irrigated land. (*John Lamb, Jr., Research Division, U.S. Soil Conservation Service, New York.*)

portable-pipe system. The cost of laying the underground pipes, of course, is relatively high, but the cost of each irrigation is less than with the portable pipe under similar conditions. A determining factor as to which system to use would be the probable total time it would be used. On land devoted to vegetables year after year, the pipes are often placed underground. Where vegetable crops are grown in rotation with feed crops, portable pipe is widely used.

No large amount of yield data has been accumulated as yet, but

preliminary reports indicate satisfactory increases in yields of potatoes, beets, spinach, and other vegetables. Total supplies of a vegetable crop are likely to be low in droughty seasons and the price correspondingly high. When most needed, therefore, irrigation has proved relatively profitable in humid areas.

SUMMARY

1. Soil water is classified as: (*a*) *Gravitational*—that which is free to percolate into tile or into the deep subsoil. (*b*) *Capillary*—that which is moved by the surface tension of the water. This is the water that crops use in growth. (*c*) *Hygroscopic*—that which is found on the surfaces of soil particles and other objects in air that contains moisture. The water held in the soil is classified also according to the pF concept (pages 79–81). Capillary water has a pF 0.0 up to pF 4.5. The permanent wilting point is at pF 4.2 (see diagram, page 79). Hygroscopic moisture covers pF 4.5 to pF 7.0 and is not used for plant growth.

2. Adding organic matter to the soil enables it to hold more water. Compacted sandy soils hold more water than loose ones.

3. Make reasonably certain that a drainage system will pay before installing it.

4. Drainage improves granulation and aeration, raises the temperature of wet soils in spring and fall, helps soil organisms in their work, reduces heaving, lessens erosion, and increases the quantity of water available to crops in dry periods.

5. Soils may be drained by means of surface ditches or furrows, and by installing underdrains. Many kinds of underdrains have been used, but only tile is widely used now.

6. Plan the drainage system according to the lay of the land. Because of the slight slope usually given tile drains, run the levels with accuracy and then lay the tile accordingly.

7. Estimate the total cost of labor and tile to determine whether drainage can be installed with a prospect of satisfactory returns.

8. Select the type of tile that is most economical in the long run in your locality.

9. For draining fair-sized areas, use a ditching machine. This is less costly than hand digging. Space the lines and determine the depth of tile in accord with the soil and the needs of the crops to be grown.

10. Give tile just the right grade or "fall" if possible, but not too much.

11. Lay the tile with care, with enough opening to admit the water but not enough to let soil work in and clog the lines.

12. Cover the inlet end of tile with a brick or stone to keep out rodents.

Cover the outlet end with hardware cloth or rods to prevent rodents from entering. Once in, certain animals will clog the tile as they cannot get out.

13. Examine tiled fields after heavy rains and in the spring. If wet spots persist, the tile may be clogged and must be dug out and cleaned to restore its usefulness.

14. Hold as much water in the soil as is desirable after rains. Nothing is gained, however, by only partial drainage.

15. Certain plants grow in water or wet soils and are called *hydrophytes*. Dry-soil plants are called *zerophytes*.

16. Some crop plants require more water than others; all of them require enormous quantities of water to produce a reasonable-sized crop. More water passes through a plant to produce a pound or ton of actual dry matter in dry climates than in humid climates.

17. Dry farming is carried on in areas with from 10 to 20 inches of annual rainfall. The temperature is important as well as the time and amount of rainfall. Ten inches is not enough in Texas but may be enough for fair crop yields in favorable years in the temperatures of North Dakota or Canada. Fallowing is essential in dry farming.

18. Choose drought-enduring crops for dry farming.

19. For dry farming select a soil of good depth that is capable of holding a great deal of water. Avoid sandy or gravelly subsoils or those that have a coarse layer within 3 or 4 feet of the surface.

20. Stir, or fallow, dry-land soils to control weeds, much as in humid areas. In dry farming, weeds rob the crop of needed moisture; they must, therefore, be killed.

21. Use care to avoid wind erosion in dry farming.

22. Use fertilizer with caution, if at all, in dry-farming areas.

23. Irrigate crops, if possible, in regions of low rainfall. Before going to the expense of installing irrigation systems, make sure that the soil and climate are suitable for profitable crop production.

24. Water for irrigation may be obtained from streams, by building reservoirs, and also from wells.

25. Give land the right slope for irrigation by cutting down high places and filling low ones. Uniform slopes are essential for furrow irrigation, and level places for flood irrigation, but sprinkling may be done anywhere.

26. In humid regions droughty periods occur in most seasons. Streams, ponds, reservoirs, and wells are suitable sources of water. Sprinkling is the common method of supplemental irrigation in humid regions.

5. Controlling Soil Erosion

SOIL erosion occurs where rain falls on bare, sloping land faster than the soil can absorb it, and muddy water runs away. In the United States, soil erosion has been a problem on sloping areas since

FIG. 71. Mature white pine, Silver Creek, Idaho. This soil is perfectly protected against erosion. (*Bureau of Entomology and Plant Quarantine, U.S. Department of Agriculture.*)

a few years after the native forest was cleared and the land brought under the plow. Similarly, in the treeless prairie area, erosion began on sloping lands a few years after the sod was turned and the hardy native grasses were destroyed. Much damage results also from wind erosion in the drier areas and on muck and sandy soils in humid regions.

Originally, the humid part of this country was covered with soil-protecting forests and grasses (Fig. 71). Under this cover, erosion took place only in the channels of streams and there waters ran clear

much of the time. In the sod of the prairies, the soil had perfect protection. Water was held back by the grass so that it reached the streams only very slowly. Channel erosion was slight. Floods must have been much less severe because of the retarding effect of the forest and the prairie in the humid part of this country.

Over 150 years ago, Washington, Jefferson, Madison, and neighboring farmers recognized the menace of soil erosion and planned for its control on their farms. On their sloping tobacco and corn soils, erosion was so severe that land was even then being abandoned because it had been severely damaged by washing. Washing on the tobacco and cotton lands of the southeast states has been and continues to be a serious soil problem. Controlling soil erosion will be discussed under the following activity headings:

1. Classifying the Kinds of Soil Erosion
2. Determining the Chief Factors Influencing Erosion
3. Estimating the Damage Done by Erosion
4. Bringing Erosion by Water under Control
5. Controlling Wind Erosion
6. Controlling Wave Erosion

1. Classifying the Kinds of Soil Erosion

Erosion is caused by water on sloping lands, by winds on muck and sandy soils in humid regions, by winds over the drier areas, and by waves on lake and ocean shore lines.

Erosion by Water. Soil erosion by water is divided into three classes—sheet, rill, and gully erosion. It must be understood, however, that these classes are not sharply defined; one kind gradually merges into another.

Sheet Erosion. The more or less uniform loss of soil from slopes is called *sheet* erosion, or sometimes *surface* erosion (Fig. 72). The loss of surface soil from slopes is often not noticed until water collects in low places and cuts into the soil below. Sheet erosion takes place on very large areas of cultivated land. Not only is plant food and rich topsoil lost, but valuable organic matter in the surface soil is lost as well. This organic matter is lost to a greater degree than is the topsoil itself. The cultivated lands of this country have suffered more loss from sheet washing than from rilling and gullying combined.

Rill Erosion. Tiny gullies or "shoestring" gullies are also referred to as *rill* erosion (Fig. 73). Rills usually form during a single rain on

land that already has lost much of the surface soil. Rills often follow the tracks and the grooves or depressions made by implements in seedbed preparation or in seeding crops. Rill washing takes place also on fairly smooth, bare slopes that have no visible depressions. This kind of washing often occurs during rains in the spring when the frost is leaving the soil. In fact, any unprotected, bare, sloping land is subject to rill erosion. The damage done by rill washing is

FIG. 72. Surface or sheet erosion. Surface erosion here has been very severe. The surface soil has all been lost from the light-colored spots, and gully erosion is under way.

often not fully appreciated. Harrowing or cultivating rill-washed land fills the channels and leaves no trace of them. But it takes surface soil from between the rills to fill them. In the next plowing, new soil from below the former plowline is brought up and mixed with what is left of the natural topsoil. Because the subsurface soil is usually lower in organic matter than the topsoil, this mixing lowers the organic-matter content and the productivity of the land. Sheet erosion and rill washing cause the same kind of damage to the soil. Rill washing is a transition between sheet erosion and gullying.

Gully Erosion. On long slopes, rills grow easily into *gullies* that are too deep and wide to cross with ordinary farm implements (Figs. 74,

FIG. 73. Rill erosion and deposition. This is severe rill erosion on a field ready to be planted to a soil-exposing crop. Note the deposition at the base of the slope. (*C. K. Bullock.*)

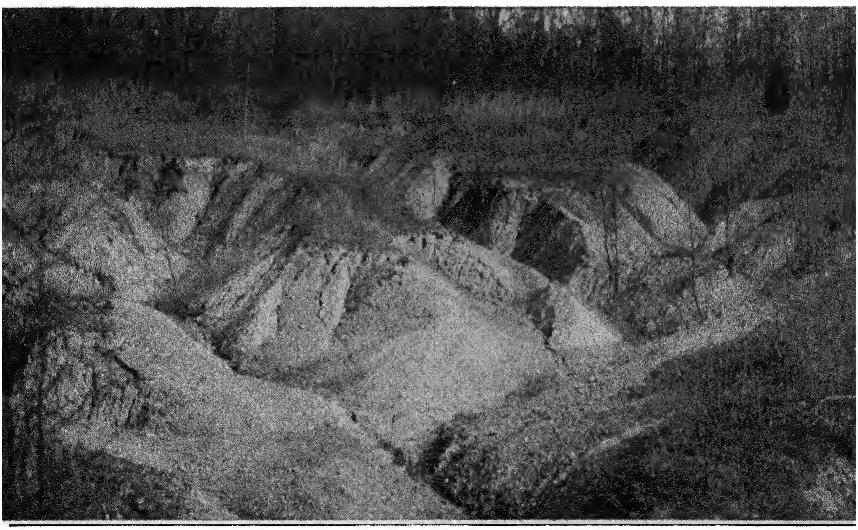


FIG. 74. Gullying on a slope of 5 per cent in Indiana. Formerly cropped land has been badly damaged. Diverting the water to a safe disposal area might solve this problem. (*M. L. Fisher, Cir. 90, Purdue University.*)

75, and 76). Rills may form very close together because they carry only small amounts of water. Gullies, in contrast, are usually much farther apart. Gullies often follow natural waterways, but such cultural depressions as dead furrows and cultivator and wheel tracks frequently develop into large gullies on sloping fields. Paths made by

FIG. 75. Gully erosion in the Death Valley National Monument. (*U.S. Department of the Interior.*)

FIG. 76. Gullying in furrows. This land was plowed for wheat. Nearly 2 inches of rain fell soon after plowing. The direction of tillage operations and the open furrows directed and intensified erosion on the slopes of this good soil.

livestock in lanes and on slopes near the farm buildings and farm roads often develop into troublesome gullies. In cropped fields sheet erosion leads to gullying.

Sheet erosion may go unobserved, but gullying is so spectacular that it attracts immediate attention. The total acreage actually occupied by gullies is small in comparison with the area of sheet-eroded lands. Gullies that are a few rods apart cut fields into small areas. Because it takes much time to farm between gullies, they add greatly to the cost of producing and harvesting crops. Gullied land,

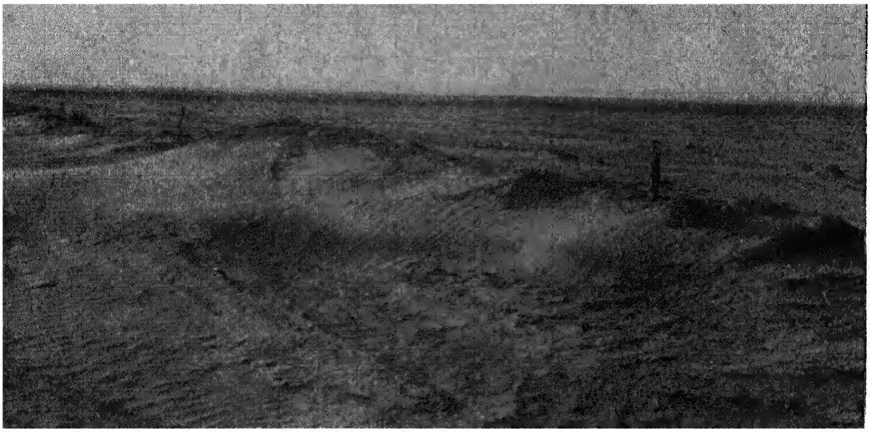


FIG. 77. Wind erosion in Texas. Trash caught by the wire fence checked the wind enough to produce this sand drift. This land was seeded to wheat in the fall of 1935. Such blowing causes severe damage to soils and ruins the crop. (*U.S. Soil Conservation Service.*)

therefore, is often abandoned for the production of cultivated crops. The land between the gullies, however, can be used for meadow or pasture and the worst of it can be reforested in order to produce some income. If gullied land is abandoned without protection one of two things takes place. Nature quickly completes its destruction or vegetation gains a foothold and eventually restores it to a degree of productivity. Medium to rich soils are far easier for nature to restore than poor ones. Favorable climatic conditions improve the chances for the natural restoration of gullied land.

Erosion by Wind. In the Great Plains and other semiarid and drier areas, finely pulverized, loose, dry, unprotected soils are subject to blowing (Fig. 77). Unusually severe blowing follows a period of

rather dry years. Less blowing, however, takes place in years of average rainfall, if the rainfall is well distributed. On humid-region croplands, sandy loams and mucks are subject to blowing if the surface is dry. In addition, the sands on ocean and lake shores are readily blown about because of the great sweep of winds and the absence of trees or other windbreaks.

Erosion by Waves. Waves work day and night throughout the years (Fig. 78). Because of their unceasing action, waves cause much erosion over the centuries. Sea and lake shores suffer most where the

FIG. 78. Wave erosion on the Atlantic shoreline of Long Island, New York. The protecting cribbing was washed away by the waves that accompanied the hurricane of 1938.

shore line consists of glacial or deeply weathered soil materials. Rocky shores resist wave erosion.

2. Determining the Chief Factors Influencing Erosion

The farmers who settled the eastern part of North America came from Great Britain, Scandinavia, and the northwestern part of the continent of Europe. There they had not known soil erosion as it has developed in this country. Most of the rainfall where they came from had been in the form of light showers. Much of the land was in grain and hay crops which usually washed very little. Because

these early farmers had not known severe soil erosion, they did not readily recognize its significance and develop measures for its control. Switzerland, however, appears to have contributed strip cropping—one of the really good means of coping with erosion by water on cropped lands. The chief factors that influence erosion are nature of the soil, slope of the land, climate and rainfall, and the type of crops grown.

Nature of the Soil. Some soils wash more readily than others under the same cropping system and a similar amount of rainfall. Coarse-textured soils may absorb moderate rains without loss of water as runoff over the surface. Yet, if a heavy rain falls on slopes of these soils faster than it is absorbed, severe surface, rill, and gully erosion take place. One reason is that coarse soils have little clay or other material to bind them together.

Medium- to fine-grained soils, especially wind- and water-deposited ones, take up moderate rains more slowly than coarse-textured ones. The rain water beats the finer particles of unprotected soils into suspension. The water is muddy and some of it runs off the land. The mud in the water is carried off the field and the finest of it goes into lakes or all the way to the sea; thus, it is forever lost to the field from which it came.

Shallow soils having slow-draining or impervious subsoils soon become saturated or filled with water. If thawing of snow or rainfall continues, runoff takes place and carries away topsoil.

The kind and condition of soils and subsoils have a strong influence on the ease and rate of their erosion.

Slope of the Land. Because water flows faster on steep than on gentle slopes, the slope has great influence on soil erosion. Not only steepness of slope but length of slope has its effect on total erosion.

Steepness of Slope. Steepness of slope is stated as a percentage. The vertical drop in feet in 100 feet of horizontal distance is the per cent of slope. A drop of 8 feet in 100 feet of horizontal distance, therefore, is defined as an 8 per cent slope.

Percentage of slope may be determined with an Abney level, a tripod level, a carpenter's level, or other fixed level. On the Abney level the slope is read directly in per cent on the scale. With the tripod or other fixed level it will be necessary to measure from the instrument to the point where the sighted line meets the surface of the land and then compute the percentage of slope. If the sighting line

of the instrument is 4 feet above the soil and the distance between the instrument and where the line intersects the surface of the soil is 40 feet, the slope is 10 per cent ($4 \div 40 \times 100 = 10\%$). Fasten any light, fixed level to the top of a 3-inch straightedge 100 inches long. Rest the other end on a smooth spot of soil and measure the distance in inches with a yardstick from the surface of the soil to the underside of the straightedge. When the bubble is in the "level" position read the distance in inches directly as per cent of slope.

On a fairly smooth slope without obstructions, the speed of flow, or the velocity of water, is largely governed by the steepness of slope. Velocity increases with added steepness of slope. The power of moving water to tear soil loose and carry it along increases rapidly with increased velocity. On the federal Soil Conservation Experiment Station near Ithaca, New York, corn was grown on the contour and losses of soil and water were determined from May through October for 3 years. The slopes were about 9 and 18 per cent respectively and the soils were open and well drained. The 9 per cent slope lost 3,500 pounds of soil an acre and the 18 per cent slope 6,500 pounds.

The direct action of gravity is closely associated with that of flowing water. On gentle slopes of 2 or 3 per cent the pull of gravity is nearly at right angles to the flow. On steep slopes of 40 or 50 per cent, gravity is acting in much more nearly the same direction as the flow. This effect is particularly important in connection with rolling pebbles or boulders along over the surface or in the beds of gullies or streams.

Length of Slope. Length of slope governs the size of the area on which water collects and flows downhill. Long slopes collect much more water than short ones. The quantity of water, as well as the steepness of slope, increases the velocity of water and its power of erosion. If water on a long slope is funneled into a depression, gullying is the usual result.

At Clarinda, Iowa, Musgrave and Norton report losses from three lengths of slope, 157, 315, and 630 feet respectively, The longer slope is four times the length of the shorter one and must have received four times as much rain water. Short slopes usually lose a higher percentage of the water that falls on them. The average loss for 2 years on 8 per cent slopes in corn was 17 tons of soil an acre a year on the 157-foot slope, 24 tons on the 315-foot slope, and 31 tons an acre on

the 630-foot slope. The loss of soil, however, does not increase directly with the length of slope.

Climate and Rainfall. In regions where the soil freezes very little over winter the soil is subject to washing throughout the year. It may be even worse where alternate freezing and thawing are accompanied by rain during much of the winter period. These conditions are found along the Gulf Coast, in the Cotton Belt states, and well northward into the Corn Belt, and erosion is often severe. In the northern states the soil is frozen 4 or 5 months. Little erosion takes place on this frozen soil except while the frost is leaving in the spring. Corn and cotton fields are subjected to rather serious erosion during open periods of winter, especially with heavy rainfall.

The type of rainfall as well as the total amount that falls influences soil erosion. On the whole, more erosion takes place in areas of high rather than low rainfall. Whatever water falls as snow obviously causes no erosion at the time. In the spring, however, the water from snow in addition to that from rain may lead to much erosion.

The intensity of rainfall, or the quantity that falls in a given time, for example 1 inch in 10 minutes, largely determines the seriousness of erosion. Areas such as Great Britain and the adjacent continent that receive the rain as gentle showers are fortunate from the standpoint of erosion. Most of the water is absorbed; little, therefore, runs off to cause erosion. An inch of water or more in 10 minutes is a larger quantity of water than most soils can absorb even if freshly plowed. This intensity and higher ones cause severe erosion on exposed erodible soils. Sections subject to the high-intensity thunderstorm type of rain have the most severe erosion.

Crops Grown. Crops vary in the degree of exposure of the soil or the degree in which they protect it. Field crops may be divided into soil-protecting and soil-exposing crops. Fruit crops are in a different group.

Soil-protecting Crops. Soil-protecting crops include clover, alfalfa, and mixtures of them with grasses and the annual grasses for hay, most permanent pasture crops, and the small-grain crops. Once established, these crops cover the soil and protect it from the beating action of raindrops. In addition, the stems and stubble check the movement of water over the soil and the roots hold it together.

Soil-exposing Crops. Among the soil-exposing crops are cotton, corn, beans, cabbage, peanuts, tobacco, potatoes, most vegetables,

and annual flowers. There is, of course, some difference in the degree of exposure of the soil during the growing season. Some of these crops, in fact, afford a fair degree of protection as they approach maturity. The soil is exposed, however, in the spring before planting, during cultivation, and again after the crops are harvested. On the whole, far more erosion takes place in or in connection with growing these soil-exposing crops than with producing soil-protecting crops.

Fruit Crops. Insofar as fruit crops are cultivated they may well be grouped with the soil-exposing crops. Particularly is this true of peaches, grapes, and other fruits that are clean tilled on sloping lands. Apples and pears that are grown in sod are regarded as nonerosive soil-protecting crops. Cane fruits vary somewhat, but, if cultivated on slopes, some erosion is certain to take place if rows are up- and downhill. About the same situation is found in nurseries producing fruit trees, roses, shrubs, and bush and cane fruits.

3. Estimating the Damage Done by Erosion

Much damage has been done and is still being done by erosion in different areas. It varies somewhat with the influences that affect erosion. A general study of soil erosion was made in 1934 by the U.S. Soil Conservation Service (Fig. 79).

Estimating the Effect of Erosion by Water. According to Fuller,[1] about one-third of the land area of this country, not including large cities, had suffered little or no erosion. Nearly one-half had been affected by sheet erosion; one-fifth of the land had lost as much as three-fourths of its topsoil and some of the subsoil. About the same total acreage had been gullied, slightly to severely, as had been affected by sheet erosion. About one-fifth of the total area of the country had been badly gullied. These are sizable proportions of the country's land surface that have suffered severely from erosion by water.

Numerous individual examples of damage by water could be cited. A few indicate the critical damage that has been done. A single heavy rain in July, 1934, washed off more than an inch of topsoil from many fields in southwestern Wisconsin. "This loss of soil capital," it was stated, "was far in excess of the value of the crops

[1] FULLER, GLENN L., Reconnaisance Erosion Survey Data, U.S. Department of Agriculture, Soil Conservation Service, SCS-MP-2, rev. July, 1935.

produced from these fields in that year."[2] In fact, except where surface soils are deep or the subsurface material is distinctly weathered, 10 per cent or more of the value of the soil was lost in that one rain. In New York, as the result of a series of heavy separate showers that lasted for 18 to 36 hours in July, 1935, in the south-central part of the state, gullies as much as 12 feet deep formed on steep slopes. Gullying

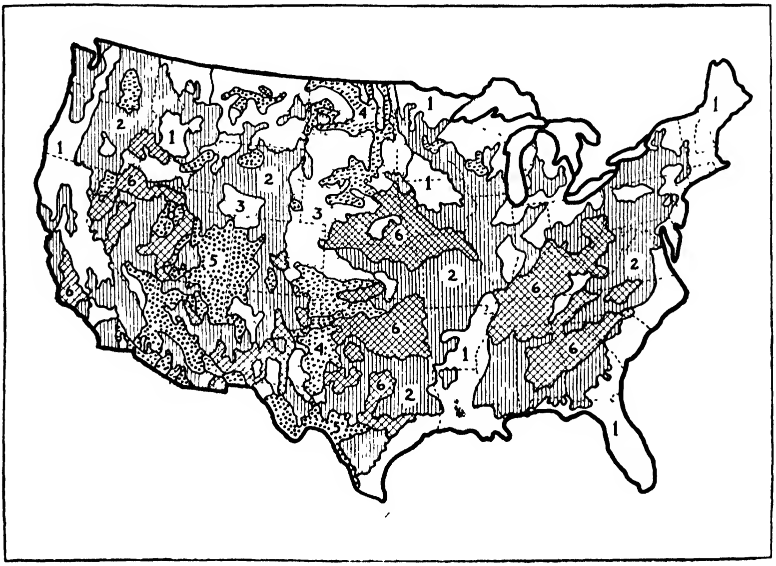


FIG. 79. Reconnaisance erosion map of the United States. (1) No serious erosion except locally; (2) moderate sheet and gully erosion, severe locally; (3) slight wind erosion, moderale surface and gully erosion; (4) moderate to severe wind erosion and gullying; (5) moderate to severe erosion, including some mountains and badlands; and (6) severe sheet and gully erosion. (*Redrawn from data by the U.S. Soil Conservation Service.*)

was particularly severe over an area of more than 3,000 square miles. The total rainfall for the storm was from 3 to 12 inches in 24 to 36 hours in the main storm area. Great damage was done, not only by gullying but by sheet and rill erosion as well. Similar examples of severe damage by erosion might be cited from practically every state in the Union.

Washing Away Fine Soil. Many soils are gravelly or stony and have a distinct shortage of fine soil material. This fine material is

[2] The University and the Erosion Problem (Science Inquiry), *University of Wisconsin Bulletin*, Series 2097, General Series 1881.

what enables soils to hold enough water and supply enough plant food for producing crops. Much loss of silt and clay from the coarser soils will render them all but incapable of producing satisfactory yields.

On many soils, raindrops beat the finer soil particles into suspension. The very finest are carried by streams to lakes or the sea where they are deposited. This highly valuable part of the soil is lost to mankind. The intermediate-sized soil material is deposited at the base of slopes or on flood plains. None of this fine soil material goes back to the fields it came from. And these fields are poorer because of the loss of the finer soil particles.

Covering Productive Soils with Stones and Sand. Although some valley farmers think they are in no danger of damage from soil erosion and that sheet erosion and gullying are of little concern to them, a definite and constant threat hangs over their lands. On some of them, rapid upland streams pour out of the hills and cut new channels across good level fields. Another threat is that of deposition of stones, sand, and finer soil materials on productive valley lands by these swift-flowing streams when they are at flood stage after heavy rains. Many acres of good valley lands are thus rendered unproductive for a long time—until fine soil is deposited by smaller floods in sufficient quantity to hold water and supply crops with plant food.

There are instances, it should be admitted, in the Missouri and Mississippi River bottoms where deep loess soil material is washed from the uplands and deposited in ponds or swamps, or on heavy soils. Such material is more productive than the soil covered by it. This type of deposition, therefore, is beneficial in the valley, but several acres in the upland were damaged or denuded for one acre in the valley that was improved. There can be little valid argument for permitting such transfer of soil to continue.

It is sometimes stated that erosion is beneficial because it makes rich valley lands. There is a grain of truth here, but what are the facts? By far the larger part of the productive valley soils were deposited in their present position many years ago; so long ago in fact, that this deposition should be credited to soil-forming processes. Some beneficial deposition is taking place, but it covers only a minor acreage; in fact, except for delta formation like that at the mouth of the Mississippi River, beneficial deposition at the present time is not important.

Filling Reservoirs. The filling of reservoirs is similar to the filling of swamps with desirable soil material (Fig. 80). Reservoirs are made for the purpose of storing water for domestic or industrial use, for irrigation, for producing water power, or for recreational purposes. Any or all of these purposes are ultimately defeated by permitting silt to fill such storage basins. Although reservoirs are built at great cost, sedimentation, unchecked, will destroy their value.

Silting is a normal process. Streams carry soil particles in suspension because the water is in motion. Once a stream enters a reservoir

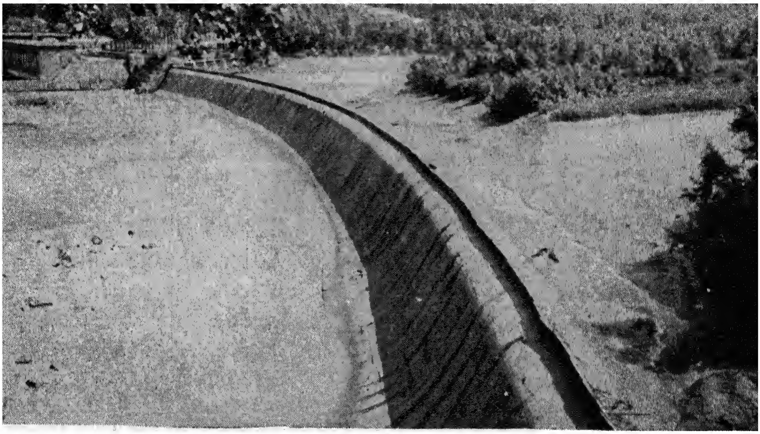


FIG. 80. Reservoir filled with silt and sand on the Dan River in Virginia. The island in the background above the dam has been there several years. (*U.S. Soil Conservation Service.*)

the motion that supports the particles is lost and the particles settle to the bottom. Sand and the coarser silt particles settle quickly, but the clay may stay in suspension for weeks as mud in the water. Even these fine particles eventually settle out and help to fill the reservoir.

In wooded areas, streams carry little sediment except that which they pick up in the scouring of the bed and banks. In farming areas, particularly if soil-exposing crops are produced on large acreages, silting of reservoirs is very rapid. Some are filled in as short a period as 15 or 20 years; however, 50 years is not an uncommon period. It is estimated that the great reservoir (originally 40 miles long) in the Mississippi River above Keokuk, Iowa, will be filled in 50 years. After this has occurred the dam will be of value only for diverting

water to the great generators. There will be no storage capacity during periods of low water to produce extra power.

Measuring the Water and Soil Lost. Although studies in soil-erosion control had been under way for a good many years, it remained for Miller and his associates at the Missouri Agricultural Experiment

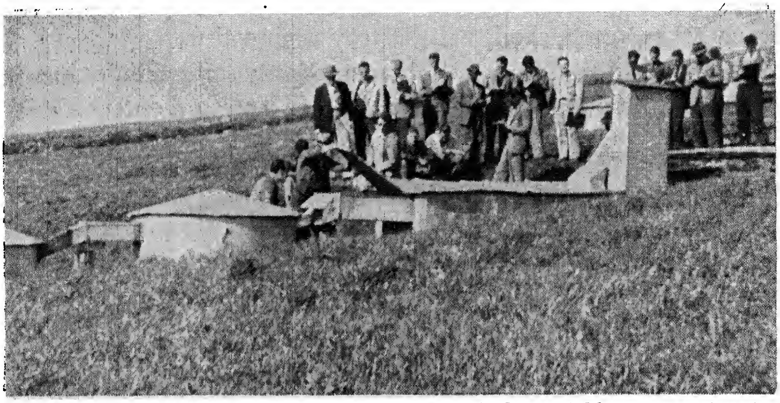


FIG. 81. Measuring losses of water and soil. A Cornell University class in soil conservation inspects the means of measuring losses of water and soil on the Soil Conservation Service field station in New York. The muddy water is funneled into the rectangular box largely embedded in the soil; from it a measured fraction is carried into the large round tank and similarly on to the smaller tank.

Station to start actual measurements of soil and water lost by erosion (Fig. 81). These measurements were begun in 1917. The results of 14 years' work are given in Table 7.

TABLE 7. LOSSES OF WATER AND SOIL FROM SEVERAL CROPPING SYSTEMS IN MISSOURI*

Tillage and cropping systems	Average yearly loss		Number of years to erode away 7 inches of soil
	Rainfall, per cent	Soil, tons per acre	
Fallow and plowed 8 inches	30.3	41.1	24
Continuous corn	29.4	19.7	50
Continuous wheat	23.3	10.1	100
Corn, wheat, clover—rotation	13.8	2.8	368
Continuous bluegrass	12.0	0.3	3,043

* MILLER, M. F., and H. H. KRUSEKOPF, The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion, *Missouri Agricultural Experiment Station Research Bulletin* 177, p. 22, 1932.

The results of the first 6 years of this experiment were reported in 1923 by F. L. Duley and M. F. Miller in *Research Bulletin* 63. In addition, much valuable historical information is found in this publication.

Losses of both water and soil were heavy from the fallow soil and from the continuous cropping of corn and wheat. From the rotation and the continuous bluegrass the losses were comparatively small. The final column of the table gives the number of years that would be required to erode off the topsoil completely under these conditions. Fifty years for corn and 100 for continuous wheat are short periods for such heavy losses of soil.

The losses by erosion of plant-food elements in the soil often receive little consideration. Miller and Krusekopf in Missouri studied the washed-off soil and determined the quantities of plant-food elements washed off the land. Their data are given in Table 8.

TABLE 8. AVERAGE POUNDS OF PLANT-FOOD ELEMENTS WASHED OFF ANNUALLY IN THE ERODED MATERIAL DURING 2 YEARS, MAY 1, 1926 TO MAY 1, 1928*

Pounds per acre

Tillage and cropping treatment	Nitrogen	Phosphorus	Potassium	Magnesium	Calcium	Sulphur
Plowed 4 inches deep (fallowed)	118.1	37.8	1,245.6	171.9	458.5	46.7
Plowed 8 inches deep (fallowed)	100.2	36.2	1,202.1	171.1	425.3	42.8
Continuous bluegrass	0.6	0.2	2.7	0.2	1.1	
Continuous wheat .	32.4	9.4	264.0	42.7	106.2	8.6
Corn, wheat, clover rotation	26.4	6.2	213.9	29.2	86.1	6.0
Continuous corn . .	65.9	19.0	605.3	87.3	220.8	16.7

* MILLER, M. F., and H. H. KRUSEKOPF, The Influence of Systems of Cropping and Methods of Culture on Surface Runoff and Soil Erosion, *Missouri Agricultural Experiment Station Research Bulletin* 177, p. 24, 1932

The extremely heavy losses of plant-food elements in the soil washed away call for attention. Severe losses took place from the fallow soil, and it made little difference whether it was plowed 4 or 8 inches deep. The losses from continuous corn, although large, were roughly about one-half those from the fallow soil. It is most interesting to note that the losses from continuous wheat were but one-half as great as from continuous corn and somewhat less than one-fourth as much as from the fallow soil. The average annual loss of plant food per acre from the rotation of corn, wheat, and clover was less than from continuous wheat. Even though one-eighth of the rainfall was lost from the soil under bluegrass, practically no plant food was washed from the sod.

Estimating the Effect of Blowing of Soils. The wind is indeed a powerful agent for the movement of soil material. It has been

estimated that winds carry 850 million tons of dust annually over the Mississippi Valley.[3]

Mild blowing of soils, like sheet erosion, escaped notice in many places for a long time. Severe blowing, however, is equally as spectacular as gully erosion. The most severe wind erosion on agricultural lands in this country has occurred in the Great Plains, although minor acreages are subject to blowing in local areas. The major wind-erosion areas are shown in Fig. 79. Area 4, which includes the Texas and Oklahoma Panhandles and the adjacent parts of New Mexico, Colorado, and Kansas, suffered severe wind erosion in the middle thirties. In addition, many smaller areas of wind erosion are shown on the map.

In the dust storms of 1934, much fine soil material was carried to the Atlantic coast. The U.S. Weather Bureau estimated that about 100 tons were suspended in the air at that time over 1 square mile in the vicinity of Washington, D.C. This soil was believed to have come from the northern Great Plains. Similar dust storms have occurred before 1934 as well as since that year. Further evidence of the power of winds to move sands and other soil material is found in the deserts of the world.

In addition, well-granulated, heavy, silty and clayey soils that are well supplied with organic matter may blow considerably in winter in humid regions if left bare. Alternate freezing and thawing dries out the surface on sunny days. Unless it is covered with snow, strong winds move the tiny granules or aggregates about. Near-by crops may be buried and drainage ditches clogged with soil. Crops are killed and time is lost in cleaning the ditches.

The total acreage of land in the United States that has been affected by wind erosion, although much smaller than that injured by water, still is a sizeable area. According to the survey already referred to, one-sixth of the area of the United States has suffered from the loss of soil that was blown away. One twenty-fifth of the country has been injured considerably and 9 million acres have been made almost worthless by wind action. These acreages are sufficient to demand action for the control, if not complete elimination, of the blowing of soils.

In addition to loss of soil, crops are injured by movement of soils

[3] The University and the Erosion Problem (Science Inquiry), *University of Wisconsin Bulletin*, Series 2097, *General Series*, 1881.

by the wind on sandy lands in humid areas and on muck lands. Sharp sand grains are hurled against the tender, young plants early in the growing season. The stems are chafed or cut, with the result that many plants are killed or badly injured and reseeding becomes necessary; otherwise no crop is obtained from the land that year. An example of this injury to crops is found on a local sandy area of thousands of acres in Central Illinois. Stems of recently germinated cowpea plants were injured so badly by the blowing sand that the crop had to be replanted to avoid a complete failure.

Similar injury to vegetable crops may occur on windswept mucklands where spring is the blowing season. The very surface of muck may dry out in but a day or two of bright sun and strong, drying wind. Only a single layer of aggregates or pieces of muck need dry out for blowing to begin. Even moist pieces may be blown about by high winds. On these lands it is the sharp, dry granules or pieces of wood that cut off the tender, little onion plants. In the dry, windy spring of 1946, onion seeds were blown out in New York and drainage ditches were clogged. The plants that are grown from seed are more seriously injured than those from onion sets. The general result is similar to that on sandy soils except that the loss to the farmer is much greater. The investment in and lack of returns from a vegetable crop are much greater per acre than from a feed crop like cowpeas. What to do to prevent such losses as these is discussed later in this chapter.

Estimating the Effect of Waves. Waves gnaw at ocean and lake shore lines almost constantly. Their action, however, is most intense and the greatest damage is done in storms. The day-in and day-out beating of the waves wears away the hardest shore lines. Sharps' Island in Chesapeake Bay had an area of 438 acres in 1848 and only 53 acres in 1903. It was estimated that it would be completely washed away by 1950. New Jersey alone, it is estimated, has lost 2,200 acres between 1840 and 1920. Because this shore line is near a large urban population, it has great recreational value and its continued loss is unfortunate. In Racine County, Wisconsin,[4] the lake shore in places has been cut back at a rate of from 3 to 10 feet a year. Some of these shore lines may be protected at heavy public expense, but that cannot be done by the farmer to protect his croplands. The cost is too great to be borne by farm lands unaided.

[4] Udden, *op. cit.*

Estimating the Effect of Hauling Away Surface Soil. In many places it is a common practice to strip off and haul away the topsoil. Such topsoil is used for surfacing lawns about private and public buildings, on exposition grounds, in cemeteries, on airports, and on shoulders of highways and parkways. In the aggregate, large quantities of topsoil are so used and large stripped areas are left with little value. Usually this topsoil is taken from valuable farm lands. Such stripping is not advisable and should be discontinued because removing all of the topsoil makes such lands almost valueless.

If the topsoil is removed and saved at the beginning of excavating operations for buildings and highways, and before low places are filled when development work is done, a sufficient quantity of surface soil will often be provided. Frequently also, a suitable finished surface can be made of a mixture of surface and subsurface soil. Little, if any, "imported" topsoil, therefore, is actually required if proper care is taken of the available original topsoil. Stripping off and hauling away is profitable for the stripper but society is the loser in the long run. The solution is to minimize, if not largely to prohibit, the removal of topsoil from large areas.

4. Bringing Erosion by Water under Control

Great damage to the sloping soils of this country has already taken place as the result of erosion by water. Each year erosion takes further toll of unprotected lands. The deterioration of our soils will continue until not only the farmer but the whole people become aroused and act to end rapid erosion. Although soils have deteriorated, total yields have increased as a result of better methods, improved strains of seeds, and heavy fertilization.

Because all our good land is needed now and will be needed in both the near and distant future, conserving every acre of good soil against that day is imperative. A start at controlling erosion by water was made 150 years ago and some effort to control it has continued, especially in the South. In the main, however, erosion continued and spread as more sloping land was planted to soil-exposing crops. Kefauver in Tennessee published a bulletin on the control of erosion in that state back in 1890. Newman published one in Arkansas in 1894. Mosier started experimental work in Illinois in 1907. The results of the first 10 years' experiments were published in *Illinois Agricultural Experiment Station Bulletin* 207 in 1918. Around the turn

of the century and during the first 20 years of it, several state and federal publications on this subject appeared. In 1917 Miller and his associates in Missouri started to measure the losses of water and soil from sloping-field soils. Some of their results already have been presented. The work of Miller and his associates paved the way for the regional soil-erosion control experimental stations that were established by the federal government in 1928. The data from this research work are now being published for the benefit of the whole country.

Although progress was slow, some erosion control has been taught in college and high school classes in soils for several years and considerable extension work along this line has been done. It was not until 1933 that special funds were made available for widespread erosion-control work. Since the beginning in 1933 the work has grown to the present great organization, the Soil Conservation Service of the U.S. Department of Agriculture under the leadership of Dr. Hugh Hammond Bennett. The service continues the research program, and the field operations work with farmers is carried on in the local soil conservation districts. Some of them are on a watershed basis, but the county soil conservation districts are growing in numbers and, therefore, in importance. Local farmers and county officials constitute the district board of directors. The technicians are members of the scientific and technical staff of the U.S. Soil Conservation Service with headquarters in Washington.

Such is the history, in part, of the soil-conservation movement in this country. A broad, all-out attack on this problem is absolutely necessary if our sloping soils are to be saved from still further damage. An outline of some of the feasible methods of controlling erosion by water is discussed in the pages that follow:

Maintaining Productivity of Soils. Thrifty, high-yielding crops not only produce needed income but their large growth protects the soil. Large top growth protects the soil from the beating action of raindrops, the root system holds the soil together against gullying, and the large growth of thrifty plants leaves relatively large quantities of residues. These residues eventually become incorporated with the soil and there provide all the benefits to the soil of increasing its organic-matter content. If fed to livestock on the farm, large crop yields provide more manure to be returned to the land than do small or medium-sized yields. Large yields are usually much more

profitable than smaller ones because such expenses as rent or interest on investment, taxes, and cost of preparing the seedbed, cultivating the land, and seeding are fixed and are no greater with large than with small yields. Only the cost of the fertilizer and similar treatment is different, and it varies with the quantity used to the acre. High yields may provide the funds for needed protective treatment for other areas on the farm.

Phosphorus may usually be used freely to advantage; some soils need potash, also; and in the more intensive cropping systems nitrogen may be required for many crops. These suggestions apply only to humid areas. In dry regions, use fertilizer only in accordance with local experience, because such soils ordinarily are well supplied with most of the plant foods.

Rotating Crops. In growing soil-exposing crops such as cotton, potatoes, corn, beans, cabbage, kafir, cowpeas, soybeans, and vegetables, work out a rotation that includes: (1) a soil-exposing crop; (2) small grain, usually regarded as a soil-protecting crop; and (3) clover, alfalfa, or other hay crop—also protecting crops. The benefits of rotation compared with either continuous corn or continuous wheat production are well shown in Table 7 (page 132). This rotation lost less than half as much soil as continuous corn and considerably less than continuous wheat. Continuous pasture or meadow, however, conserves the soil even better than a rotation.

Provide longer rotations, with soil-exposing crops included for a smaller proportion of the time and soil-protecting crops included for more of the time. This practice holds the soil better than does a shorter rotation. Society cannot afford a loss so rapid that the productive topsoil could be washed away in 50 years from soil in continuous corn. Unusually deep soils that are partially weathered to considerable depths are not utterly ruined by loss of the topsoil. Soils with hard-pan from 6 to 10 inches under the surface or bedrock within 24 inches are nearly ruined by loss of the top 6 or 8 inches of soil. The broader benefits of rotating crops are listed in Chap. 12.

Tilling the Land and Seeding Crops on the Contour. Plowing, preparing the seedbed, seeding crops, and harvesting on the contour[5] aid in the control of erosion by water (Figs. 82 and 83). Nearly all tillage operations produce some furrows and ridges. On the contour, the furrows catch and hold water until it soaks into the

[5] A contour line is a level one across a slope.

soil. If furrows are up- and downhill the water runs down them like the ready-made rills that they, in fact, are. Much rich topsoil is lost with up- and downhill tillage that might be saved by contour tillage. Plowing uphill leaves small furrows and readily directs the water into the soil between the furrow slices. Throwing the furrow uphill is feasible on slopes up to 18 per cent by using an extension on the moldboard. Moreover, plowing is the only practical way of moving soil uphill in our agriculture. In the Orient and in France, soil is carried or hauled back onto the hills from which it has been

FIG. 82. Contour-planted grapes. Grapes on the contour with a cover crop have fairly good protection against erosion.

washed. Because of labor costs we cannot put soil back on sloping fields once it has been washed off them.

Contour potato rows as ordinarily ridged hold 2 inches of water on moderately steep slopes, and even more on gentler slopes. Much water and soil is lost from potato and other crop rows that angle downhill, because such large quantities of water collect in and flow down the rows. Eventually it breaks over and gullying results. The effect of direction of rows is well illustrated by results published by Musgrave and Norton. Their data are given in Table 9.

Although the figures in Table 9 are for only 2 years, they are striking. No soil and little water was lost from the contour rows of

corn. This is compared directly with the same length of slope on which up- and downhill rows lost 17 tons of topsoil. At this rate of erosion, 7 inches of topsoil will be lost from 60 corn crops on an 8 per cent slope 157 feet long on this Iowa soil. It must be admitted, however, that contouring alone cannot control all the erosion on cropped lands.

TABLE 9. WATER AND SOIL LOST FROM LAND IN CORN, CLARINDA, IOWA*
(Average for 1933 and 1935 Slope 8 per cent)

Length of slope, feet	Direction of crop rows	Water lost, inches	Tons of soil lost per acre
630	Up- and downhill	2.16	31.4
315	Up- and downhill	2 65	24.1
157.5	Up- and downhill	3 55	17 3
157 5	Rows on contour	0 05	0 0

* MUSGRAVE, G W, and R A NORTON, Soil and Water Conservation Investigations, *U S Department of Agriculture Technical Bulletin* 558, p 51, 1937.

Another point of interest is that the moisture content of the soil, as an average for 3 years, was 2¼ per cent higher on the contour than on the up- and downhill rows. This is enough water to produce more than 1,000 pounds of dry forage to the acre. In dry years this difference in moisture content can increase the yield considerably.

On the U.S. Soil Conservation Service Experiment Field Station near Ithaca, New York, contour potato rows were compared with up- and downhill rows. As an average of one dry and one wet year, the yield was 23 bushels higher on contour rows than on the up- and downhill rows. In the dry year the yield was 36 bushels higher on the contoured rows. The loss of soil was 28,000 pounds an acre on the up- and downhill rows in the wet year and 202 pounds an acre on the contour rows. In the dry year, the loss of soil was 10,000 pounds to the acre from the up- and downhill rows and none from the contour rows. This soil is a flaggy silt loam and has a low percentage of fine material of the size that was washed away. On the basis of a loss of nearly 10 tons of soil an acre a year, the fine part of the surface soil from the up- and downhill potato rows would be washed away from about 45 potato crops. After that the surface material would be entirely too coarse to hold enough water to grow potatoes. The plants of close-growing crops and clean-tilled ones also check the movement of water and thus encourage its absorption by the soil.

Even meadow seedings on the contour hold water to better advantage than if they are sown up- and downhill.

Rows may be kept definitely on the contour or given a slight but uniform slope. Rows on the contour hold water until it soaks into the soil. If there is no danger of the soil staying wet in the fall so as to interfere with the digging of potatoes, use contour rows to control erosion. If there is danger of excessive wetness at digging time, give

FIG. 83. Old strip cropping (field stripping) on farm of Ulmer brothers in Pennsylvania. Field stripping, which is not always definitely on the contour, has been practiced in parts of Pennsylvania for nearly three-quarters of a century, from 25 to 50 years in others. Grassed waterways in the old gullies across the strips are visible in the background.

the rows a slope of about ½ of 1 per cent—just enough to let the excess water run off the potato land. This water, however, must be conducted safely to an outlet that will not permit erosion.

Strip Cropping on the Contour. The origin of strip cropping probably is not known, although it may have developed in Switzerland. Unquestionably, many farmers developed the idea wholly independently of others (Fig. 83).

William R. Linnert laid out his farm near Danville, Pennsylvania, in contour strips in 1885 and farmed it that way for 55 years, or

throughout the rest of his lifetime. These strips were strictly on the contour and 140 feet wide. No gullying was in evidence in 1939 or 1940, but on a slope of 25 per cent on wide strips some surface washing had taken place in corn.

For varying periods of 30 to 40 years or more, farmers in Mayberry Township south of Danville, near Jersey Shore, Washington, and Williamsport, Pennsylvania, have farmed strips that run across

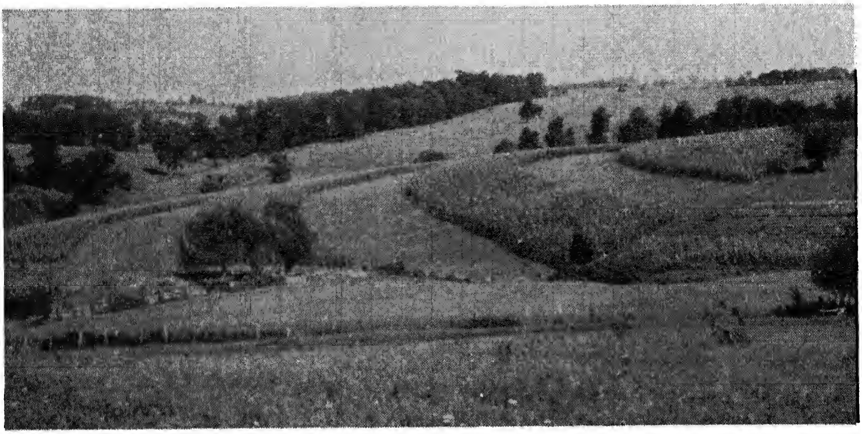


FIG. 84. Contour strip cropping. Corn and alfalfa are alternated on this farm. (*U.S. Soil Conservation Service.*)

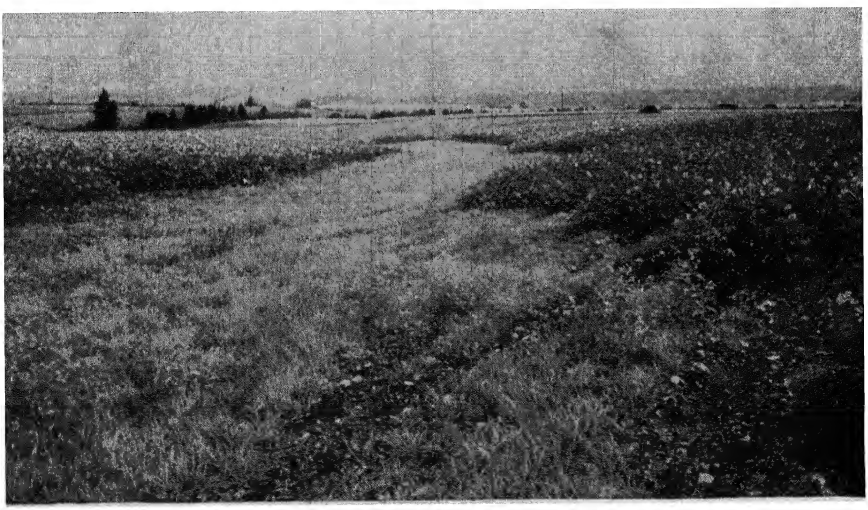


FIG. 85. Grassed waterway in potatoes in Maine. This waterway is ample to carry the water without danger of washing at the edges in the cultivated land. (*U.S. Soil Conservation Service.*)

the main slopes and are near the contour in many places. Strip cropping has been practiced also in West Virginia, eastern Ohio, Minnesota, and New York. The strip cropping in Belmont County, Ohio, said to have been started about 1870, may be the oldest in this country. That in Minnesota, however, followed closely. Wider strips were used in Pennsylvania and New York than in most of the other areas; too wide, in fact, for the best control of sheet erosion.

Good Width of Strips to Use. Although the *best* width of strips to use may never be determined, good widths have been worked out (Figs. 84 and 85). Widths depend on the intensity of rainfall, the erodibility of the soil, the crop rotation followed (particularly the proportion of soil-exposing crops grown), the slope of the land, and the climate. To fit strip widths to so many factors is difficult. Experimental work has thrown some light on the problem, as did also the early strip cropping already mentioned When buffer strips are used in soil-exposing crops, the strips of the soil-protecting crops can be somewhat wider than otherwise (Table 9). The results of experimental work on the Soil Conservation Field Station near Marcellus, New York are given in Table 10.

TABLE 10. EFFECT OF STEEPNESS AND LENGTH OF SLOPE ON THE LOSS OF SOIL DURING THE PERIOD MAY THROUGH OCTOBER
(Honeoye Silt Loam)*

Slope, per cent	Rainfall, inches	Length of slope or width of strips		
		36.3 feet	72.6 feet	210 feet
		Tons of soil lost per acre		
16.8	17.63	14.1	20.6	33.3
9.3	18.36	1.3	1.0	0.9
4.7	18.53	1.0	0.4	0.4

* FREE, G. R., E. A. CARLETON, JOHN LAMB, JR., and A. F. GUSTAFSON, Experiments in the Control of Erosion in Central New York, *Cornell University Agricultural Experiment Station Bulletin* 831, 1946

On the basis of a knowledge of the climate, rainfall, soils, crops, and rotation practices in the North, the writer has proposed a basic width of 100 feet[6] on well-drained soil with a slope of 10 per cent.

[6] This width was reduced by 25 feet from a previous proposal which had been a compromise with farmers' objections to narrow strips. GUSTAFSON, A. F., "Conservation of the Soil," p. 134, McGraw-Hill Book Company, Inc., New York, 1937.

The width was to be varied 5 feet for each per cent steeper or leveler slope. The formula works out as shown in Table 11.

TABLE 11. PROVISIONAL APPROXIMATE STRIP WIDTHS FOR DIFFERENT SLOPES AND SOILS IN THE NORTH

Per cent of slope	Strip width, feet: 1. Well-drained soil, resistant to erosion	2. Moderately drained soil, moderate erodibility	3. Slow drainage or water-laid soil, easily eroded
3	135*	110*	85*
5	125	100	75
8	110	85	60
10	100	75	50
12	90	65	
15	75	50	
17	65		
60	50		

* It may well be that 100 to 110 feet is a desirable maximum width

Formulas that approximate these widths are in general use in the North. The difference between the highest and lowest erodibility is great enough to provide for some increase in intensity of rainfall, such as is experienced in the South and Southeast. These widths are only approximate. The widths used should provide for multiples of the width of the most important implement or that which is least flexible. Width of strip is relatively unimportant for harrows, but for potato sprayers or 2- or 4-row planters, the need for multiples of implement widths is greater. If potato rows are 3 feet apart and a 10-row sprayer is used, multiples of 30 feet are essential; otherwise time is wasted in double spraying or in spraying less than the full 10 rows at one time. Strips of 60, 90, or 120 feet would be used instead of the width shown for a given condition in Table 11. With 4-row, 3-foot planters, multiples of 12 feet give convenient strip widths to use. Strips of 60, 72, 96, or 108 feet would be used instead of the exact widths in the table.

Another reason for holding the greatest width of strip to 100 feet is the advantage of having approximately the same acreage in each crop every year. Uniformity in acreages is far more easily accomplished if there are no strips that vary greatly in acreage from that of the average-sized ones.

Usually, in areas of intense rains, erodible soils, and soil-exposing crops, much narrower strips must be used to obtain a fair degree of erosion control or other means must be used in addition.

Arranging the Crops on Strips. Strip cropping is feasible as an erosion-control measure only where protecting crops may be alternated with exposing ones. Alternating corn with dry beans, potatoes, or cabbage does not ordinarily give a satisfactory degree of protection. Avoid plowing two adjacent strips at the same time in the season wherever possible. A good cropping arrangement on strips is given in the following tabulations.

ARRANGEMENT OF CROPS IN A 4-YEAR ROTATION

Strips	First year	Second year	Third year	Fourth year
		First series of strips		
1	Clean-tilled crop	Small grain	Legume	Grass
2	Legume for hay	Grass for hay	Clean-tilled crop	Grain
3	Clean-tilled crop	Small grain	Legume	Grass
4	Legume for hay	Grass	Clean-tilled crop	Grain
5	Clean-tilled crop	Small grain	Legume	Grass
6	Legume for hay	Grass	Clean-tilled crop	Grain
7	Clean-tilled crop	Small grain	Legume	Grass
8	Legume for hay	Grass	Clean-tilled crop	Grain
		Second series of strips		
9	Small grain	Legume	Grass	Clean-tilled crop
10	Grass for hay	Clean-tilled crop	Grain	Legume
11	Small grain	Legume	Grass	Clean-tilled crop
12	Grass	Clean-tilled crop	Grain	Legume
13	Small grain	Legume	Grass	Clean-tilled crop
14	Grass	Clean-tilled crop	Grain	Legume
15	Small grain	Legume	Grass	Clean-tilled crop
16	Grass	Clean-tilled crop	Grain	Legume
		Arrangement of crops on a single series of strips		
1	Clean-tilled crop	Grain	Legume	Grass
2	Grass	Clean-tilled crop	Grain	Legume
3	Grain	Legume	Grass	Clean-tilled crop
4	Legume	Grass	Clean-tilled crop	Grain
5	Clean-tilled crop	Grain	Legume	Grass
6	Grass	Clean-tilled crop	Grain	Legume
7	Grain	Legume	Grass	Clean-tilled crop
8	Legume	Grass	Clean-tilled crop	Grain

In the 4-year rotation the *clean-tilled* crop may be any soil-exposing crop that fits into this type of cropping system, such as cotton, tobacco, corn, kafir, potatoes, beans, or truck crops. The *small grain* may be wheat, oats, barley, rye, or winter oats or barley in their area of adaptation. The *legume* may be a clover or alfalfa but not an annual legume such as cowpeas or soybeans. The latter, for this purpose, would better serve as a clean-tilled crop. The *grass* for hay should be

Fig. 86. Contour strip cropping in detail. Note the fine growth of corn; also, that this lad is throwing his furrow uphill, which is a good way to help control soil erosion. (*J. I. Case Co.*)

timothy, brome, or other perennial grass but not an annual such as Sudan grass or millet.

Use either of these arrangements for a 4-year rotation. If there are two fields or slopes that have 4, 8, 12, or a multiple of 4 strips, the split arrangement has some advantages. All of any one crop in a season is in the same field or on the same slope and time is saved compared with having part of a crop at some distance. For the small farm or one that has but a single series of strips, the second arrangement is suitable. In fact, the latter will usually give better protection for the soil (Fig. 86).

Three-year rotations are used on strips, but the clean-tilled crop and small grain are adjacent to each other every year. In the spring before the grain becomes well established, the soil is exposed to erosion on both the grain and the clean-tilled crop strips.

In a 5-year rotation of a clean-tilled crop, grain, legumes, and two additional years of hay crops, a suitable arrangement can be made. Such an arrangement is shown here.

ARRANGEMENT OF CROPS IN A 5-YEAR ROTATION

Strip	First year	Second year	Third year	Fourth year	Fifth year
1	Corn	Beans	Winter grain	I Hay crop	II Hay crop
2	I Hay crop	II Hay crop	Corn	Beans	Winter grain
3	Winter grain	I Hay crop	II Hay crop	Corn	Beans
4	Beans	Winter grain	I Hay crop	II Hay crop	Corn
5	II Hay crop	Corn	Beans	Winter grain	I Hay crop

Longer rotations, such as 6- or 7-year ones, with more hay, can be used, but they require multiples of the number of years in the rotation. The longer rotations limit the acreage that can be devoted to the clean-tilled crop which is often the cash crop, or the one that produces the highest return during the entire rotation. Long rotations rather than short ones are followed on steep or less productive land. The long ones fit into systems that include livestock for which a large acreage of hay is needed.

In certain cash-crop areas, two clean-tilled, high-return crops may be grown in a 5-year rotation. This arrangement gives a higher proportion of cash-crop acreage than does the 4-year rotation and, therefore, may be preferred in cash-crop areas with good soils.

Criticisms have been made of strip cropping on the ground that time was wasted. Careful checks, however, show that labor is slightly more efficient on contour strips than on ordinary, small square fields. Adjusting strip widths to fit large implements will improve the efficiency of labor. Farming on the contour is somewhat more economical of power than up- and downhill work. Even if contour-strip cropping were slightly more expensive, it should be practiced because of the saving of soil and plant food and because of the higher yields obtained. Also, there is more stability in contour strip-cropped farming than in ordinary up- and downhill farming.

Making Contour Furrows. Contour furrows are used in pastures in the drier areas of the country. They serve two purposes: (1) saving water for use by the pasture plants, and (2) holding back water for reducing the crests of floods. Summer rains are often of the thunderstorm type, yet the total summer rainfall is not enough for heavy pasture production. The grass needs all that falls and more. Saving water by any feasible means, therefore, is in the interest of the cattle industry. The water held by the furrows does materially increase the growth of grasses (Fig. 87).

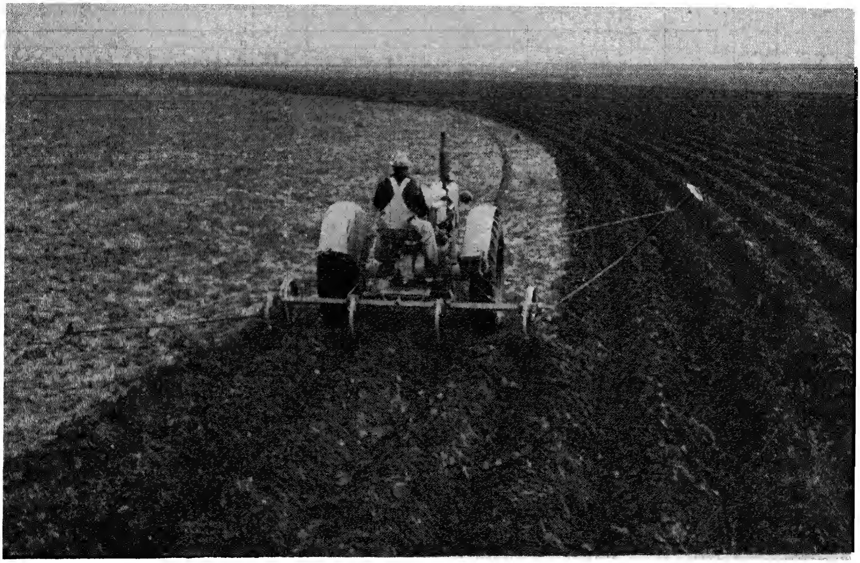


FIG. 87. Contour furrowing for conserving water in a dry area. A four-bottor lister furrows a field at a rapid rate. (*Minneapolis-Moline Power Implement Co.*)

Make furrows with the moldboard plow or with the lister. It i not difficult for furrows to hold 2 inches or more of rain on gentl slopes. On steep slopes (about 25 per cent) ordinary moldboard o lister furrows have little capacity for water. Any saving of watei however, is a real benefit to pastures in dry areas.

Contour furrows are used in a small way in the humid area of th country. In the East, however, most pastures have such steep slope that furrows hold little water. Also, the cattle soon wear down th ridge so there is left little more than a path such as cattle usually mak on the contour around steep slopes. Any flat place like this on a slop checks the flow of water and causes additional absorption of watei

Where pastures are mowed for the control of weeds and for managing grazing, farmers do not like furrows. The mower leaves high stubble in the bottom of the furrow and such stubble interferes with grazing by animals. Coarse grasses and weeds are likely to obtain a foothold under the protection of this stubble. On nearly level slow-draining soils, water stands in these contour furrows for considerable periods. This permits the growth of sedges and other water-loving plants that have low, if any, grazing value.

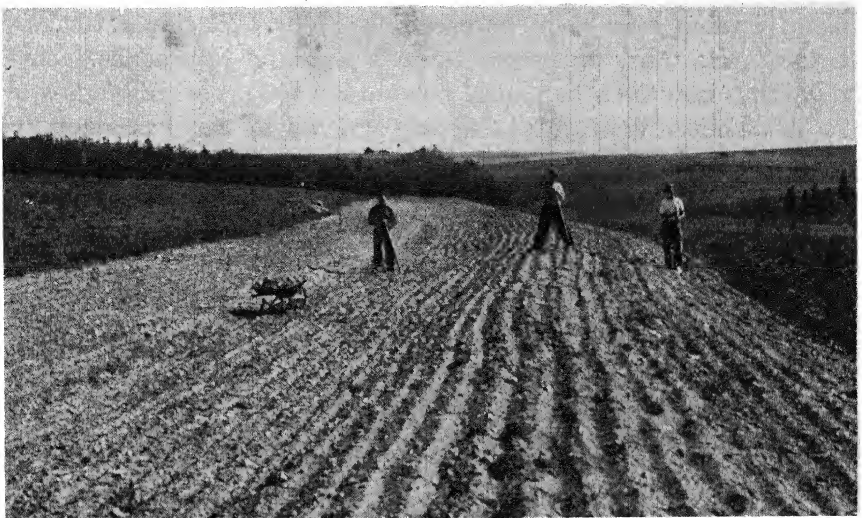


FIG. 88. Diversion channel. Diversion channels are usually given a slope of 1 per cent. Both channel and embankment are seeded to a grass and legume cover.

On closely grazed moderate to steep slopes in dry areas, flash rains run off rapidly and cause severe losses such as flooding cities, villages, and farms in the lower valleys. In these areas, furrows on grazing lands have held back enough water to reduce flood damage to the very great benefit of the people who live in the valleys.

Building Diversions. Build diversions wherever they are needed (Fig. 88). They are often laid out with a uniform slope of 1 foot in 100 feet of channel. The channel, together with both slopes of the embankment and a filter strip 20 to 30 feet wide or more above the channel, is sown to grasses and one or more fine-growing adapted legumes. Manure this entire area, fertilize, and give it any additional

treatment that is needed by the legumes and grasses. The purpose of the grass is to prevent erosion both in and out of the channel. The purpose of the filter strip is to check the water and remove the silt before the water reaches the channel. If no filter strip is used and soil-exposing crops are grown down to the edge of the channel it is often clogged by soil washed down the slope into it. Clogging may result in overtopping the embankment and washing it out. Costly repairs will then be needed to restore the channel. Diversions are placed between contour strips to remove the water and prevent it from running over strips lower on the slope. Placing a diversion below each third or fourth strip is a common practice. Small diversions may even be placed below each strip. More land would be taken out of the regular cropping system with small channels, but better control of erosion is likely to be accomplished than with a few large diversions farther apart. There is the same need for protected outlets with diversions as with terraces, and these are discussed in the next section.

Terracing Sloping Land. Terraces are of three types— bench, level, and drainage. In the bench type a slope is worked into a series of level steps with a steep slope on the lower side. Bench terraces are little used now, although they may conceivably be the ultimate in erosion control on intensively cultivated lands, even in this country.

The level, or closed-end, terrace is used to catch water and hold it until it is absorbed by the soil. A place for it may be developed in dry areas or where there is special need to catch water and bring about its absorption by the soil for the benefit of crops, wells, springs, and streams, in dry periods.

As ordinarily used, terraces are of the diversion or drainage type; they are made the same as the more common diversions which consist of a broad, flat-bottomed channel. The slope is varied; it steepens from the head toward the outlet. This increases the carrying capacity of the channel. Terraces are cultivated and cropped the same as the rest of the terraced field.

P. H. Mangum, in North Carolina, developed the broad-base terrace and built the first one in 1885. It was still in use in 1936. Narrow channels or broad furrows had previously been used but they were not successful. The water was so concentrated that much washing or scouring took place in the channel. For building the embank-

ment of the Mangum terrace the soil is taken from the channel and also from the lower side.

The Nichols terrace was developed by M. L. Nichols, now director of research of the U.S. Soil Conservation Service. For making the embankment most of the soil is taken out of the channel (Figs. 89 and 90). This method of building has some advantages over the Mangum type; there is less danger of the embankment being washed out by overtopping.

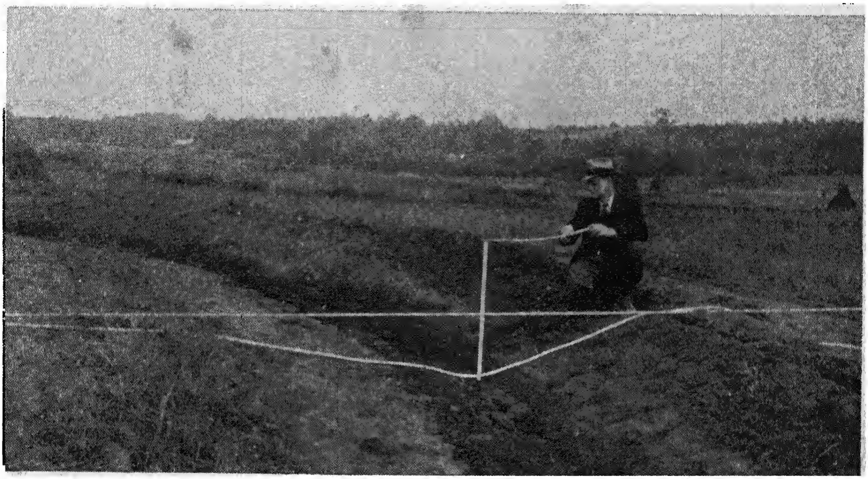


FIG. 89. This terrace is of the Nichols type for drainage. All the soil for the embankment comes from the upper side. The sides of these channels have so little slope that they are cropped along with the remainder of the field. (*Caterpillar Tractor Co.*)

The distance between terraces is governed by the intensity of rainfall. The channels must be placed close enough together to carry all the runoff from the area between them. The rapidity of the soil's absorption of water must be considered. Less water runs off to be taken care of by the terrace channel on soils that absorb water quickly. And on this kind of soil there is a large amount of absorption in the terrace channel itself.

The crops, too, receive consideration. Soil-exposing crops such as cotton, tobacco, peanuts, potatoes, corn, and others permit more runoff than do small grains, legumes, and grasses. If a high proportion of soil-exposing crops is to be grown in the rotation, the terraces are made narrower than they are if a goodly proportion of soil-protecting crops is to be grown.

Little terracing is done on slopes steeper than 12 per cent, and 10 per cent is better. In parts of the Southwest, because of the intensity of rainfall, the nature of the soil, and the almost exclusive growing of soil-exposing crops, 5 per cent is about the upper limit of slope for safe terracing.

Laying out, constructing, and checking the finished terrace are tasks for the engineer or other persons trained in the use of levels and experienced in the art of terracing.

FIG. 90. Building a Nichols terrace. Here a terracer is being drawn by a caterpillar tractor. The embankment is being built from the upper side. The nearly finished channel is 18 inches deep. (*Caterpillar Tractor Co.*)

Controlling Gullies. Gullies result from the concentration of water on sloping lands in dead furrows, wheel tracks, paths made by livestock, and any depressions that are made in the tillage work. If neglected, gullies may deepen rapidly and become more and more troublesome. Moreover, the expense of filling large gullies is often prohibitive.

The first consideration is to check the flow of water in them. We have seen that increasing the velocity of water greatly increases erosion. Decreasing the velocity of water, likewise, rapidly reduces or stops erosion; therefore, anything that reduces velocity is helpful. Tramp straw into small gullies to control them. In larger gullies stake down the straw to hold it from being washed away. In still

larger ones, cover the straw with brush held in place by poles that are wired to sturdy posts set in the gully (Figs. 91 and 92). This is the brush dam. Place plenty of brush or other nonerosive material below the dam as an apron to catch the water as it falls over the dam and to prevent washing. In pastures or other areas that are not cultivated, use slips of willow or other adapted, sprouting wood to produce a living dam.

Shrubs, vines, and trees may be used to advantage. Select growthy materials that spread by underground rootstocks or above-

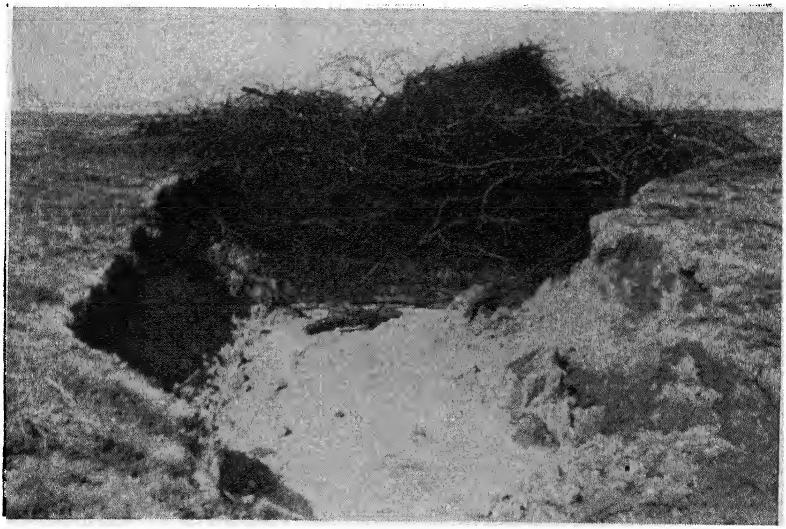


FIG. 91. Checking gully erosion with brush. The prunings from an apple orchard here are helping to check erosion in this gully. First lining a gully with wet straw or fine brush and then tramping the brush in as tightly as possible helps to fill gullies.

ground runners; they are especially desirable. Adapted species can be found for most areas. Native plants can be used, but many people prefer nursery-grown planting stock. It is claimed that the latter starts off better and makes more rapid growth.

Leguminous shrubs and trees are of great value in gully control. The black locust grows well over a wide area in this country. It is a legume and, if inoculated, makes rapid growth in the subsoil of gullies; growth is better, however, in the less acid than in strongly acid soils. Either cut back the black locust to produce a shrubby growth or allow it to grow naturally, as desired. As a tree it is useful

for fence posts or grape stakes. Another point worthy of consideration is that the locust has an open crown and lets in the light. Grasses tend to come in readily under these trees. Rose acacia and redbud, or Judas tree, are also leguminous plants which grow well over a considerable area.

Construct check dams of woven wire, logs, slabs from a sawmill, stone, or concrete (Fig. 93). Woven wire fence has been used with

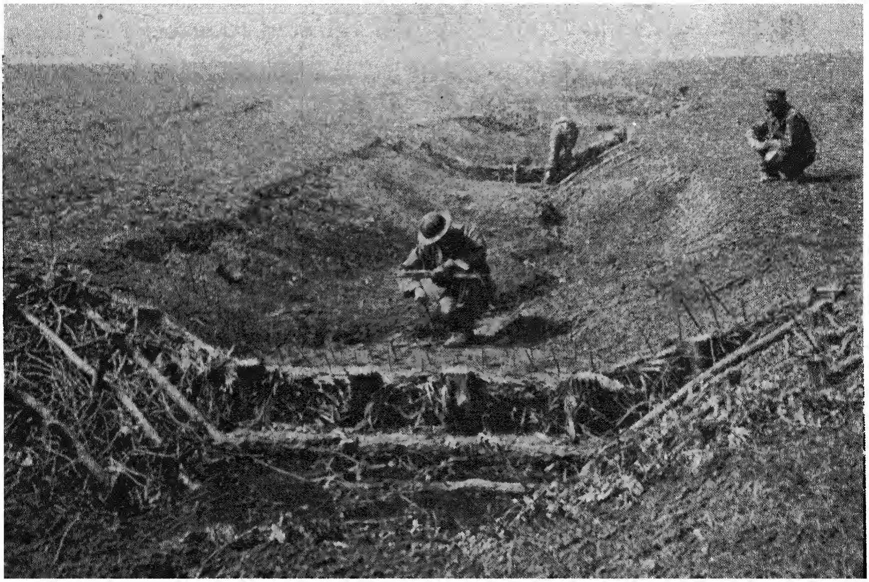


Fig. 92. Brush dam for checking and filling gullies. Considerable work but little cash outlay is required for such a dam. Four dams are required to control this gully. The edges have been eased to obtain a grass cover. Manuring and fertilizing hasten the establishment of a cover on the soil. (*U.S. Soil Conservation Service.*)

straw for many years. Unless vegetation becomes established in the soil material held, these dams are only temporary. Log dams serve for a period of years but eventually rot out, and then the dam fails. Concrete and stone dams are expensive and because of inadequate anchorage or peculiarly erosive soil may fail after a few years. Dams of soil with a draw-down pipe are successfully used in many places for the control of moderate-sized gullies. In most gullies, vegetation is important because it usually becomes more effective with additional years of growth. Moderate-sized gullies in deep soils may be plowed in and farmed in the usual way or left as grassed waterways (Fig. 94).

FIG. 93. The formless concrete dam for checking gully erosion. A check dam like this is made by smoothing the surface, using woven fence for reinforcement and stiff concrete that is fitted onto the prepared surface. Below the dam is seen a stilling pool to prevent erosion at the foot of the dam. (*Portland Cement Association.*)

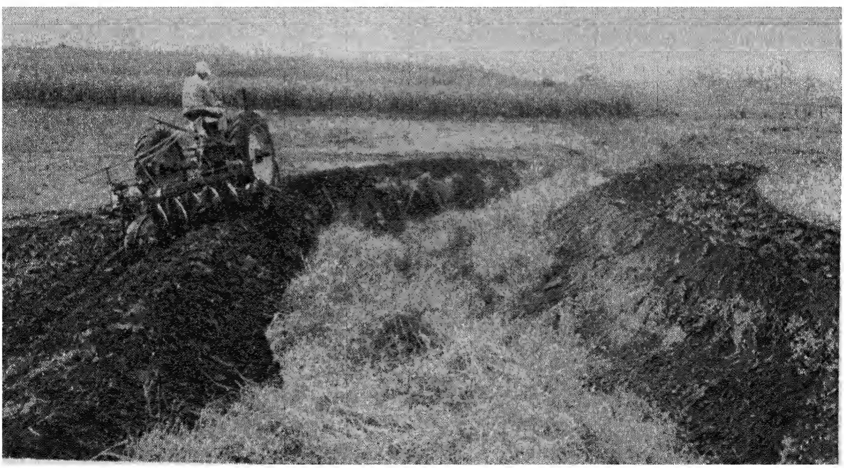


FIG. 94. Filling a gully with a disk plow. In deep soils, gullies may be plowed in and established as grassed waterways until they are completely filled. (*Deere and Co.*)

Because its effectiveness improves with growth, make extensive use of vegetation in the control and filling of gullies.

Controlling Road- and Stream-bank Erosion. Controlling erosion on road and stream banks is a common problem in hilly areas. Vegetative protection is helpful on both types of bare banks. On road cuts and fills, use vegetation for protection on slopes of 50 per cent on well-drained soils or about 30 per cent in poorly drained soils. Seed long-lived hay grasses and legumes and cut them with

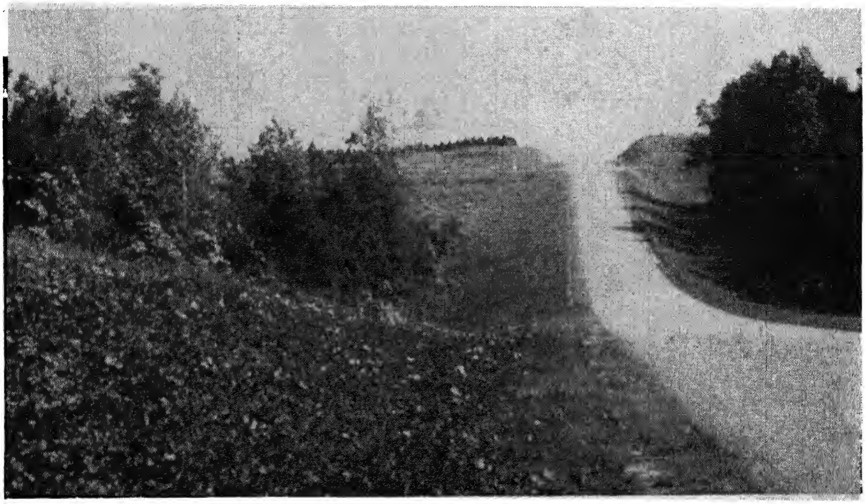


FIG. 95. Kudzu controlling erosion on road bank in Alabama. Kudzu is established and later completely protects the cut from erosion. This plant is equally useful throughout the south for protecting the sides of fills and the banks of gullies. In fact, kudzu helps to fill gullies rapidly. (*U.S. Soil Conservation Service.*)

an ordinary mower. Many of the plants that are useful in gully control serve the same purpose on road and stream banks. In the South, kudzu is particularly effective in holding soil in place on road banks and in filling gullies (Fig. 95). Although not a legume, the trailing honeysuckle (*Lonicera japonica halliana*) is used effectively on road banks in the South and also well into the northern states.

Stream banks, because of the cutting by the stream, often require additional protection at and below the high-water line. Large stones, cribbing (Fig. 96), and walls laid of loose stones, as well as concrete walls are used. Concrete walls, especially on gravel, however, are often undercut by the current in flood stage, and they finally fail.

The use of brush that is held in place often builds up soil on which vegetation may be established. On small streams, basket-willow slips may be used with good effect in such fills and in other areas too, provided that the cutting is not too rapid. On large streams, jetties as well as other elaborate and correspondingly expensive engineering works are needed to control active stream-bank erosion.

FIG. 96. Stream-bank control. Cribbing of concrete has been built to protect this road. This may prove effective, although the erosion beyond the cribbing casts a cloud over the project.

Controlling the Silting of Reservoirs. Reservoirs in forested areas fill with sediment slowly compared with those in agricultural sections (Fig. 80). Reservoirs in areas of severe erosion are filled in from 15 to 25 years and others in 40 or 50 years. In forested areas the life of a reservoir is several times as great as in farming sections. Control erosion on farm lands in the drainage area and thereby reduce silting to a minimum. Fertilize meadows and pastures to develop a thick, resistant turf. Use shrubs (Fig. 97) or reforest all bare or steep slopes and check erosion in stream channels. All of these practices delay the silting of reservoirs. In the larger reservoirs, sand gates, or controlled openings, are used for the purpose of drawing off a considerable amount of silt, clay, and fine sand soon after heavy rainstorms that carry much sediment into the reservoir.

FIG. 97. An excellent wildlife border. Such borders can be planted on the strip of a field adjacent to woods on which crops do not thrive because of competition and shade. The multiflora rose has a prominent place in this type of planting in the humid northern part of the country.

Alleviating Floods. Holding water on farm and forest lands near the headwaters and along streams by erosion-control methods reduces the crest of floods. Not only do these measures delay runoff water in getting into the streams but they encourage more of it to soak into the soil. Because less water runs off there is less floodwater to cause damage in the valleys. Provide detention dams to collect and hold floodwater. It is released shortly after the water in other streams has gone on to the larger rivers or to the sea. Such dams should reduce the crest of floods. Many dams, however, are needed to influence greatly the height of floods in the larger valleys.

5. Controlling Wind Erosion

The reduction of the velocity of winds has the same relation to erosion by the wind as does the reduction of the velocity of water to the checking of erosion by water. Strong winds do more damage than gentle breezes. Although erosion by water occurs only following rains, winds blow almost continuously in the more seriously affected areas.

Protecting the Soil with Vegetation. Vegetation is the best means of protecting the soil against blowing. Even short grass or

stubble checks the movement of the air near the surface of the soil. The wind, therefore, is not strong enough to move the particles of soil. In the Great Plains, badly damaged lands may be reclaimed and restored to productivity by establishing long-lived legumes and grasses. Plant native grasses because they are probably more effective than others. On the range, control grazing to the extent that *all the soil* is well protected.

FIG. 98. Furrows in Colorado for controlling wind erosion. Such furrows are made at approximately right angles to the prevailing direction of the wind. When the furrows are blown full, new ones are made. (*U.S. Soil Conservation Service.*)

Keeping Surface of the Soil Rough. Bare, smooth, loose sands and pulverized finer soils are easily moved by winds. Avoid pulverizing the soil in dry, windy areas. Leave the soil slightly cloddy and rough on the surface to check blowing. These lumps are too large to move easily and help to protect the finer material.

Making Furrows. Making furrows with a plow or lister across the main direction of the wind is good practice (Fig. 98). The ridges check the movement of air over the surface. Sand and soil consequently drop into the bottom of the furrows. When the furrows are nearly filled make new ones. In areas where the wind shifts considerably make furrows across the regular ones. Then, when the wind shifts these cross furrows catch and hold the soil.

Practicing Trashy Cultivation. In fields of wheat or other small grain, leave the stubble and the combined straw on the surface. Prepare the seedbed under this cover of trash and seed through it by means of a disk drill. The organic matter is thus left on the surface to protect the soil against wind action. If the grain is drilled in furrows, the furrows also help hold the soil in place.

Tilling and Seeding across Wind Direction. Do all tillage work and seeding across the main direction of the wind. Advantage is thus taken of any depressions or furrows, however slight, for catch-

Fig. 99. Windbreak in Nebraska to reduce the effects of winds. Such windbreaks check wind movement over considerable distances to the leeward. They conserve moisture as well as soils. There are six rows of poplars beyond six rows of evergreens. (*U.S. Soil Conservation Service.*)

ing and holding soil. Moreover, as soon as the crop is up it checks the movement of air over the land. This not only holds the soil but helps to check the loss of water from the soil. If the wind shifts frequently, use occasional strips of cross-drilled grain; this will help to reduce the loss of soil.

Cropping in Strips. Cropping in strips is similar to strip cropping for control of erosion by water. For checking wind erosion, run the strips across the main direction of the wind. Cropped strips may be alternated with fallow ones or, where the supply of water is sufficient, soil-protecting crops are alternated with soil-exposing ones. Soil from fallow strips is caught and held by the cropped strips. Kafir, a good dry-land crop, serves as a windbreak and protects the fallow

strip to the leeward. If fallow strips are too wide, soil blown from them may cover and smother the crop or the blown soil may form a drift or dune in the crop.

Using Windbreaks. In an area where trees thrive, use them as windbreaks to check the velocity of the wind for a goodly distance to the leeward (Fig. 99). Not only does this lower the loss of soil but it lowers the evaporation from the soil. Reduced evaporation provides more moisture for the crop which makes better growth and protects the soil.

FIG. 100. Beach grass controlling blowing of sand on Long Island, New York. American beach grass planted at random or anything that checks the velocity of the wind reduces sand movement.

Plant only trees that are known to succeed in the locality. Use the tallest, densest-topped trees in the middle of the windbreak, use low-growing trees toward the edge, and set shrubs on the border of windbreaks. Evergreens give the windbreak more complete effectiveness over the winter season.

The distance to use between windbreaks will vary with their eventual height and with soil, climate, and cropping conditions in the area.

Holding Sand in Humid Areas. The principles for the control of blowing in the Great Plains apply also to the holding of sand against blowing in humid areas (Figs. 100 and 101). American beach grass is most widely planted. Always set it at random; never in rows in any

direction. The wind shifts at times to a direction parallel to the rows, which then afford no appreciable protection against blowing. Such nitrogen-gathering plants as the trailing wild bean (*Strophostyles helvola*), black locust, beach pea, and the partridge pea (*Cassia fasiculata*) help to furnish nitrogen to the beach grass. Many other plants, including certain wild lespedezas, goldenrod (*Solidago* sempervirens), and many shrubs, including beach plum, grow on sands of Long Island and presumably on other sands under similar climatic conditions.

Windbreaks are helpful. Woven picket fence is much used in temporary locations. After the sand has piled up against the fence,

Fig. 101. Beach pea with beach grass. A legume such as the beach pea fixes nitrogen for the beach grass and makes the grass more effective in holding the sand. It should be planted with the grass.

lift the fence to make use of its full height. Brush is effectively used as a cover on sand and also as a windbreak. Plantings of locusts or forest trees may be made in straw that is held in place, or in brush. The straw or brush holds the sand until the trees are large enough to give complete protection.

In the spring, crops are injured by blowing sand. A few hours of blowing of sharp sand grains against tender plants kills them. Unless the crop is replanted or another put in its place the use of the land is lost for the season. Provide windbreaks, trashy cover, and strip cropping—each may be used to advantage. With winter grain, windbreaks of picket fence or strips of cross-seeded grain or strips of grain broadcast ahead of the regular drilling of the crop should help to prevent undue movement of the sand.

Keeping Muck Soils from Blowing. Muck soils in the northern part of the United States blow and cause heavy loss to early crops in late spring. At that season, sun and wind dry the surface quickly so that blowing begins. Granules of muck and bits of wood are light and blow easily. They are sharp and easily injure and finally kill tender young plants.

Windbreaks of basket willow, rye, and picket fence are effectively used to check the velocity of the wind (Fig. 102). The willows and

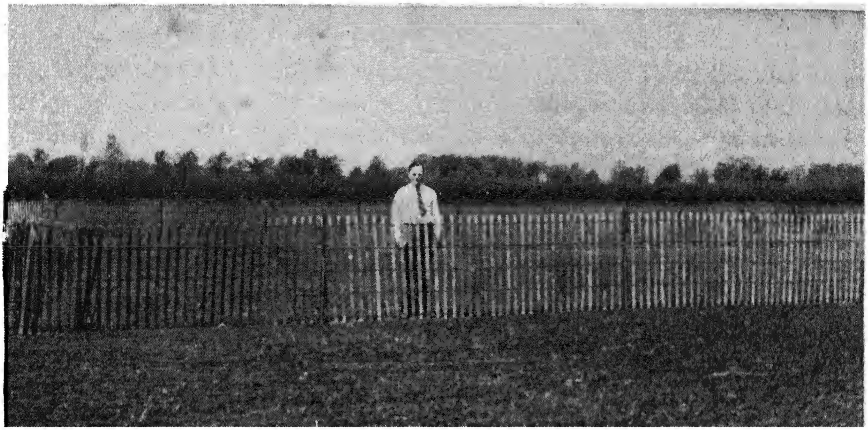


FIG. 102. Willow and woven picket fence controlling erosion on muckland. The windbreaks grow from slips of basket willow. Tree-type willows occupy too much of this valuable land. Movement of the muck must be controlled during the early part of the season until crops protect themselves.

picket fence are widely used. Other shrubs are used but this willow is popular because of its rapid growth. In some areas there is a growing tendency to depend entirely on picket fences.

6. Controlling Wave Erosion

Controlling wave erosion is often a public problem because it involves the protection of wharf and dock facilities and recreation beaches. The necessary engineering structures can be built at costs that are in line with the benefits that may be expected. No such expenditures can be justified to protect farm land. If wave action is not too strong, use adapted or native vegetation. Make use of sweet clover and other clovers along with grasses and leguminous trees and shrubs. On fresh-water lake shores, willows protected by boulders

obtain a foothold and protect the shore line. On ocean coast lines the problem is complicated by the salt in the sea water.

SUMMARY

1. Erosion began on the sloping lands of this country soon after they were cleared and planted to clean-tilled crops.

2. Erosion is caused by running water, wind, and waves. That caused by water is divided into sheet, rill, and gully erosion.

3. Erosion is influenced by the nature of the soil, by the length and steepness of the slope, by the climate, especially by rainfall, and by the crops grown. Some soils wash much more easily than others and must be managed with more care to avoid destructive erosion. Long slopes, particularly steep ones, require protection. In climates where the soil is frozen for several months less erosion takes place than where little freezing occurs or where there is a long period of alternate freezing and thawing.

Heavy beating rains cause flash runoff and severe erosion. Long, light rains may be completely absorbed by the soil without runoff and, therefore, without erosion. It is only runoff water that causes erosion.

4. Soil-protecting crops permit far less erosion than do soil-exposing crops when they are grown on similar slopes on the same kind of soil. Fruits, like most other crops, may be planted on the contour to protect the land from destructive erosion on steep slopes.

5. Much damage has been done and is still being done by runoff water. This damage includes the loss of fine topsoil, organic matter, and plant food. Plant food can be restored but, once lost, the fine soil is gone forever. At the mouth of rapidly flowing streams, valuable land is covered by stones and sand and is thus made unproductive for years to come. Washing on farm lands in the drainage area of reservoirs eventually fills them with silt and sand. This makes them worthless as reservoirs.

6. During recent years losses of soil and water have been measured from sloping lands.

7. Blowing of soils has three detrimental effects: (*a*) Valuable soil and organic matter are blown away; (*b*) drainage channels, especially in muck areas and along highways are clogged by wind-blown material; and (*c*) sand and other particles are driven against plants and eventually kill them.

8. Wave action is nearly continuous, but it is during storms that it is especially destructive. The farmer is at the mercy of the waves because he cannot make a large outlay to protect his land.

9. Bringing erosion by water under control requires the adoption of a number of protective methods: (*a*) Keep the soil productive by fertilizing, manuring, and liming, if needed. (*b*) Rotate soil-protecting crops, including a leguminous hay crop, with soil-exposing crops. (*c*) Plow for, seed, culti-

vate, and harvest crops on the contour. (*d*) Divide slopes into fairly narrow contour strips wherever feasible and alternate soil-protecting with soil-exposing crops on them. Never plow adjacent strips at the same time. (*e*) Build diversion or terrace channels to carry water off slopes to safe waterways. (*f*) Control gullies by keeping water out of them wherever feasible, and check the movement of water in gullies by means of straw, brush, or live vegetation. If these measures are ineffective, build dams. (*g*) Help in the control of silting reservoirs by holding soil and water back on the farm or other lands in the drainage area of reservoirs. These measures, plus holding water in swamps or by temporary detention dams, aid in reducing the damage by floods.

10. To control wind erosion: (*a*) Keep a protective vegetative cover on the land. (*b*) Keep the surface of cultivated lands rough to check wind movement. (*c*) Make furrows to catch and hold soil. (*d*) Practice trashy cultivation wherever feasible, especially in dry-farming areas. (*e*) Plant crops in strips at right angles to the principal wind direction. (*f*) Set out windbreaks of fairly thick-growing shrubs or low trees to check the wind and thus reduce its power to move soils. Woven picket fence is especially useful as a temporary windbreak in cultivated fields.

11. On sandy shores, plant beach grass with wild legumes, native or adapted shrubs, especially nitrogen-fixing ones, and use woven picket fences.

12. On muck lands, plant basket willow or other shrubs for windbreaks at right angles to the main wind direction and use picket fences and rows of grain to check wind movement and to reduce damage to crops.

13. Use boulders, cribbing, and vegetation to check wave action. Vegetation may be more useful on fresh-water than on salt-water shore lines.

6. Managing Acid Soils

SOILS vary widely in degree of acidity and alkalinity. Humid northern soils tend to be acid, but dry-region soils are often alkaline. Some young, humid, northern soils contain enough limestone to give them an alkaline reaction. Others which were formed from sandstones, shales, and other acid rocks are acid. Very old soils, however, whether they were formed from limestones or from acid rocks, bear no relationship to the rock from which they were formed. Most of them in the North Temperate Zone are acid. Many tropical soils, however, are essentially neutral. Managing acid soils will be discussed under the following headings:

1. Determining the Causes and Nature of Soil Acidity
2. Determining Extent and Effect of Acidity
3. Identifying the Forms of Lime
4. Comparing Values of Liming Materials
5. Correcting Soil Acidity
6. Liming for Special Crops
7. Growing Acid-loving Plants
8. Liming to Control Plant Diseases

1. Determining the Causes and Nature of Soil Acidity

As already indicated, northern humid-region soils that were formed from acidic rocks are acid except as alkaline materials may have been mixed with them or in some way introduced into the soil material. Much acid is carried into soils in rain water. Acids in the air are dissolved in raindrops as they fall. Also, acids are formed in the soil during the breakdown of organic matter. In moist soils these acids, including carbon dioxide, dissolve immediately in the soil moisture.

Determining the Causes of Acidity. The loss of lime from soils and the formation of carbon dioxide in soils are leading causes of soil acidity.

Loss of Lime. These acids attack and combine with calcium, magnesium, sodium, potassium and other materials that tend to make soils alkaline or are said to be *basic* in nature. Carbon dioxide (CO_2) is dissolved in, or combines with, water (H_2O) to form carbonic acid (H_2CO_3). This acid attacks, or combines with, basic materials. In the case of limestone, the calcium carbonate and magnesium carbonates are relatively insoluble in water. Otherwise limestone would be of no value as a building material. The reaction may be represented thus:

$$\text{Calcium carbonate} + \text{carbonic acid} = \text{Calcium bicarbonate}$$
$$CaCO_3 + H_2CO_3 = Ca(HCO_3)_2$$

The insoluble limestone is changed to the calcium bicarbonate, which is readily soluble in water. Calcium and other basic materials may thus be carried out of and lost from the soil. In this way not only are fragments of basic materials in soils dissolved, but massive limestone deposits are brought into solution by carbon dioxide and other acids. The limestone disappears, leaving behind the impurities of the rock as residues. These residues are usually good but acid soils. Some soils are so young that they have not lost all of the fragments of limestone in the soil material. Such soils, therefore, are alkaline. In time, however, the limestone and other basic materials are so completely leached away that the soil is acid.

In the drainage tanks, or lysimeters, at the Cornell University Agricultural Experiment Station, a cropped soil lost calcium and magnesium carbonates at a rate of 725 pounds an acre a year on the average. Bare soils lost even more bases; the average annual loss from bare Dunkirk soil was 1,220 pounds an acre a year. Cropping, therefore, reduced the average yearly loss from 1,220 to 725 pounds an acre. By far the larger part of the calcium and magnesium in soils, or that put on them as limestone, is not used by crops but is lost by leaching.

Formation of Carbon Dioxide. Carbon dioxide is formed in the decay of organic matter in or on the soil and in the burning of coal and wood and other organic matter. In addition all animals breathe out carbon dioxide. The acid that is formed in the soil is in an ideal position for developing soil acidity. The carbonic acid and other acids in the soil are in intimate contact with the soil minerals and are constantly acting on them in humid regions except when the soil is frozen. The mineral part of moist soils is, in reality, bathed in a

weak solution of acids. The more acid present, the more the concentration of H^+ ions tends to exceed that of OH^- ions and to produce an acid condition of the soil. After the basic material has been removed, the H^+ ions tend to accumulate and to produce an increasing degree of soil acidity.

Determining the Nature of Acidity. Soil acidity is of two kinds, active and reserve.

Active Acidity. The active acidity results from the concentration of H^+ ions in excess of the concentration of the OH^- ions in the soil solution or the moisture in the soil. Although the excess of H^+ ions may cause a high degree of acidity, only a small quantity of limestone or other basic material is required for complete neutralization of the acid.

Active soil acidity is expressed in pH units. A pH of 7 corresponds to neutrality or a perfect balance between H^+ and OH^- ions (Fig.

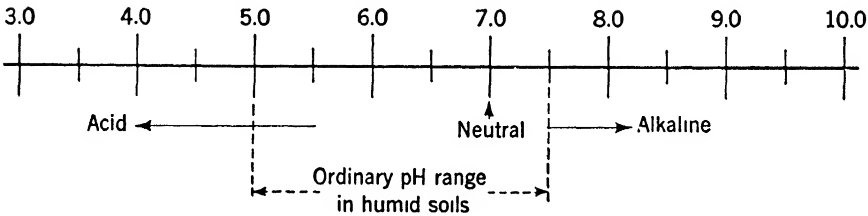


FIG. 103. A section of the pH scale. Different degrees of acidity and alkalinity are expressed in pH units.

103). The pH readings 6.0, 5.0, 4.0, and 3.0 represent increasing degrees of acidity. At pH 5 the acidity is 10 times as great as at pH 6, at pH 4, 100 times, and at pH 3, 1,000 times as great as at pH 6. In contrast, the numbers larger than 7.0 such as pH 7.5, pH 8.0, and pH 9.0 represent increasing degrees of alkalinity. It is at first confusing that increasing acidity is expressed by smaller and smaller numbers, although increased alkalinity is expressed by larger and larger numbers. These relations, however, must be remembered in order correctly to understand this method of stating the acidity and alkalinity of soils.

For humid soils a pH range of a little below 5 to somewhat above 7.0 or 7.5 is common. The extreme normal range for these soils is from somewhat under pH 4 to a little above pH 8.5. Although greater extremes are found they are rather rare. The terms *high*,

moderate, and *slight* are used to express acidity in soils and may be correlated with the pH of mineral soils as follows:

Very high acidity, under.	pH 4 5	Slight acidity........	pH 6 0 to 7.0
High acidity . .	pH 4 5 to 5.0	Neutrality	pH 7.0
Moderate to high acidity ..	pH 5 0 to 5.5	Slight alkalinity......	pH 7 0 to 7 5
Moderate acidity. ..	pH 5 5 to 6 0	Strong alkalinity.	pH 7.5 and above

Reserve Acidity. The H^+ ions that are held mainly by the colloidal matter of the soil represent the reserve acidity. These ions are more or less closely held and are not so free to move about as are the ions in the soil moisture. A very small quantity of a liming material added to an acid soil corrects, or neutralizes, its active acidity. After the active acidity has been neutralized, H^+ ions are released by the clay part of the soil so that the soil moisture becomes acid again. Supplying H^+ ions to the soil moisture is an important role that is played by reserve acidity. It helps also to explain why colloidal matter is of great consequence in soils.

To correct active acidity as it comes from the reserve in the soil is the main purpose of using lime on soils. Farmers put on from 1 to 2 tons or more of limestone to the acre (depending on its fineness). The Ca^{++} ions exchange places with the H^+ ions in the soil and thus correct acidity. The amount of active acidity in soils at any one moment is very slight compared with the amount of reserve acidity in strongly acid soils. Yet, a fairly definite relationship exists between the active and the reserve acidity of soils.

2. Determining Extent and Effect of Acidity

Precise chemical apparatus is used for determining the active acidity which is expressed in pH units. Dyes, or indicators, change color at different degrees of acidity. For fine divisions of pH readings a group of indicators is used. Each indicator covers only a part of the pH scale that is needed for soils. A mixture of indicators has been used to make approximate pH determinations. Carefully made laboratory readings are more accurate than most of those made in the field. The pH of soils varies somewhat from week to week during the growing season.

Hydrogen ions in moderate concentration do not appear to be harmful to plants. Instead, it is the conditions in soils that accompany acidity that damage plants. Such substances as aluminum, manganese, and iron are relatively insoluble at slight acidity, pH 6

to pH 7, but at higher acidities they are fairly soluble. Some of these soluble compounds of aluminum, manganese, and iron are toxic, or poisonous, to plants. At moderate acidity such as a little under pH 6, many crops thrive, but at high acidity such as around pH 5, sensitive crops are injured. Soluble aluminum, especially, has been regarded as mainly responsible for the injury to crops that accompanies high soil acidity.

Crops may be divided into three groups on the basis of their growth on soils of different degrees of acidity or their response to liming. The crops listed at the top of each column in the accompanying tabulation are generally more sensitive to acidity than are those lower down in the columns.

LIME REQUIREMENT OR RESPONSE OF CROPS TO SOIL ACIDITY

Group 1 requires high active calcium content or slight acidity	Group 2 grows well at moderate to slightly higher acidity and moderate calcium content		Group 3* requires very high acidity and low active calcium content
Alfalfa	Barley	White clover	Raspberries
Sweet clover	Bluegrass	Lespedeza	Blueberries
Red clover	Beans (garden)	Tomatoes	Cranberries
Onions	Sweet corn	Millet	Holly
Beets	Carrot	Turnips	Rhododendron
Celery	Soybeans	Squash	Azalea
Spinach	Alsike clover	Cowpeas	Laurel
Lettuce	Corn	Cucumber	
Cauliflower	Oats	Buckwheat	
Cabbage	Wheat	Vetch	
Eggplant	Orchard grass	Watermelon	
Muskmelon	Timothy	Redtop	
Chard	Potatoes	Bent grass	
	Poverty grass		

* Little differentiation as to active acidity requirements in group 3. Adapted from work by Hartwell and Associates, Rhode Island Agricultural Experiment Station

Although a best pH may be found for many plants under certain soil conditions, plants are capable of good growth over a moderately wide range of acidity. An abundance of readily available mineral plant foods tends to widen this range in acidity.

Effect of Acidity on Availablity of Phosphorous. Phosphorus in soils is most readily available to crops in the area of slight acidity. Its availability decreases rapidly under pH 5.5, and phosphorus is nearly

insoluble at high acidity or under pH 5. It is in this zone of high acidity that phosphorus combines with iron and aluminum to form insoluble compounds that are unavailable to many crops.

On the alkaline side of neutrality, phosphorus combines with calcium. Although this compound is not readily available to most crops, it is far more so than the iron and aluminum phosphates.

3. Identifying the Forms of Lime

Compounds of calcium and magnesium are generally used for correcting soil acidity because they are abundant in many sections and consequently inexpensive.

Limestone and Lime. The term *lime* is popularly used for the materials that are put on soils to correct their acidity. Limestones, burned lime, hydrated lime, blast-furnace slag, and some other by-product materials are used.

Carbonate Liming Materials. In limestone, the active elements calcium and magnesium occur as carbonates, $CaCO_3$ and $MgCaO_3$[1] (Figs. 104, and 105). Some limestones are mainly calcium carbonate, and are spoken of as *high calcium* limestones. Others have from a few per cent to 45 per cent of magnesium carbonate and are called *dolomitic*, or *high magnesium*, limestones. Limestones contain impurities; some much, others very little. From 90 to nearly 100 per cent of carbonates is common. Percentages lower than 90 are not well suited to use on the soil because they carry 200 pounds or more of worthless material to the ton.

In preparation for use on the soil, limestones are ground to varying degrees of fineness. Much research work has been done to determine the effect of fineness of grinding on the benefits of liming to crop growth. It is well known that the fine material, that which passes through a screen with 100 holes to the inch or 10,000 holes to the square inch, is more beneficial to crops than coarser material. A limestone of high purity, one-half of which passes through the 100-mesh screen, 90 per cent through the 20-mesh, and all of it through the 10-mesh screen, is considered suitable for use on feed crops in the northeastern states. The lime requirement of crops in that area is based on this quality and fineness of limestones. Coarser stones are used, but larger quantities must be put on to get effects on the first hay

[1] One unit of calcium or magnesium is combined chemically with 1 unit of carbon and 3 units of oxygen.

FIG. 104. Limestone quarries of the Michigan Limestone and Chemical Company, Rogers City, Michigan. The quarry face is 100 feet high at this point; in places it is 200 feet. When this picture was taken, there were between 25 and 30 miles of workable quarry face. In some places the overburden of soil material is as much as 60 feet deep. Removing this overburden is a costly item in open-pit mining. (*Michigan Limestone & Chemical Co.*)

FIG. 105. Loading cars with limestone in the quarry. This electric shovel weighs 1,500 tons and is capable of moving 25 tons in each dipperful. (*Michigan Limestone & Chemical Co.*),

crop. Although it is expensive, much limestone in the Northeast is handled in paper bags. Screenings and ground stone that have from less than 30 to about 50 per cent of material that passes through a 50-mesh screen are used in some sections, notably the Middle West. Very large quantities of such material to the acre are needed for red clover or alfalfa on soils that have an acidity of pH 5 or higher. Fine grinding is somewhat costly; farmers, therefore, use the size that appears to be most economical under their local conditions. Hauling to the farm and spreading on the land are part of the cost of liming

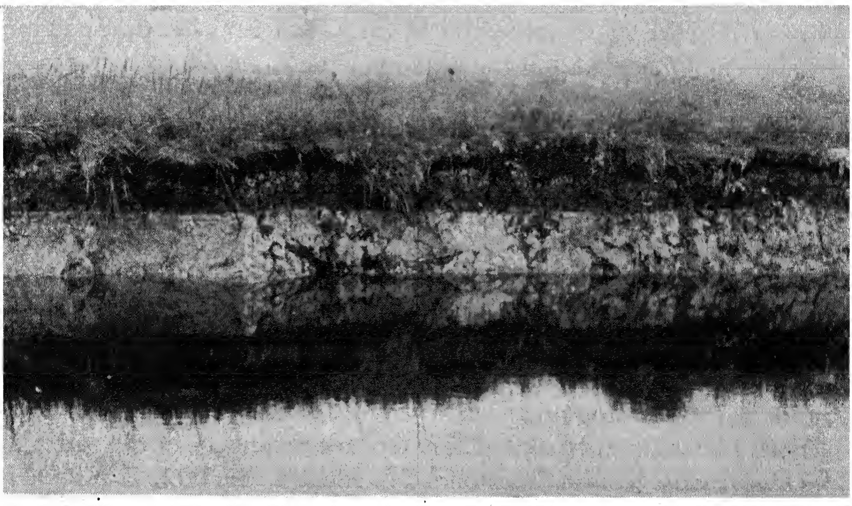


FIG. 106. Marl under muck. Here is a relatively thin covering of muck overlying a bed of marl of good purity. It is usually expensive to take marl out of the water and prepare it for spreading on acid soils.

the soil. The kind of lime or limestone, therefore, that costs least per acre per crop of clover or alfalfa spread on the land is usually used.

Marl. Marl is found under muck in swamps in some areas and is largely calcium carbonate (Fig. 106). Because of its location, it usually contains silt and clay that were washed in, and much marl is of low purity. Pound for pound, however, the calcium in marl is equal in value to that in limestone. The difficulty in the use of marl is getting it out of the water in which it was formed. Occasionally, however, a marl deposit is so located that it can be drained, and this is more easily worked than a flooded deposit. Because of the expense of drying marl it is usually used within easy trucking distance from the deposit.

Shells. Oyster shells, either burned or ground to proper fineness, are a suitable liming material. They have from 90 to 95 per cent of calcium carbonate.

Burned Lime. Burned lime is made by burning limestone. Much of it is used for building purposes, but some of it is used on the soil. Burned lime, lump lime, and quicklime are all calcium oxide, CaO. In the process of burning, carbon dioxide is driven out of the stone as gas. On burning, 100 pounds of pure calcium carbonate loses 44 pounds of carbon dioxide, and 56 pounds of calcium oxide remains. Because it is the calcium that corrects acidity, the 56 pounds of oxide have the same total value in the soil as 100 pounds of calcium carbonate. One pound of the oxide has the same neutralizing value as 1.784 pounds of calcium carbonate.

Hydrated Lime. Hydrated lime and hydrate are popular names for calcium hydroxide, $Ca(OH)_2$.[2] It is formed by adding water, as such or in the form of steam, to burned lime. The calcium content of hydrate is usually expressed in terms of calcium oxide. The analysis on a bag of hydrate is given as per cent of calcium oxide. Multiply the percentage of calcium oxide in hydrated lime by 1.784 (as stated under burned lime) to obtain its equivalent calcium carbonate value. This relationship applies only to the actual calcium compounds in these liming materials which contain impurities of no value.

Both burned and hydrated lime act more quickly in the soil than does even finely ground limestone. Except on vegetable crops where the pH of the soil must be changed quickly, it is difficult to evaluate this quicker action of burned and hydrated limes.

Factory-made hydrated lime is shipped in paper bags. Some lime is burned and slaked or hydrated on the farm and is spread directly on the land without bagging. Burned lime is sometimes placed in small piles on the field, covered with soil, and allowed to slake. When it is completely hydrated it is spread with a shovel. Because of the handwork, this method is seldom used at the present time.

Blast-furnace Slag. Blast-furnace slag is formed in the process of making pig iron from iron ore and limestone. Slag contains much calcium silicate, some calcium carbonate, and iron. Because slag is hard, fine grinding is desirable. Recent experimental work indicates that blast-furnace slag has a high value for correcting soil acidity.

[2] Calcium hydroxide consists of 1 unit of calcium and 2 OH radicals. Each radical consists of 1 unit of oxygen combined with 1 unit of hydrogen.

Wood Ashes. Fresh hardwood ashes contain lime, about 4 per cent of potash, and 1.5 to 2 per cent of phosphoric acid. They contain other substances also that are of value to crops. Ton for ton, fresh hardwood ashes have about the same value for correcting acidity as a good, finely ground limestone.

Gypsum and Salt. Gypsum and salt have little if any value as liming materials. They may even cause acidity if some of the basic materials were leached away. Little effect, however, is usually expected.

4. Comparing Values of Liming Materials

It is the calcium and the magnesium in liming materials that bring about correction of acidity in soils. If limestones are of suitable fineness their effectiveness depends on the total quantity of calcium and magnesium in them. Because of their quicker action, however, hydrate and burned lime are of greater value for some crops. If there is serious danger of clubroot on cabbage, cauliflower, and other crops because of soil acidity, many growers use hydrated lime. The burned forms in sufficient quantity quickly correct acidity and raise the pH to a point that controls clubroot. Limestone is much slower in changing the pH of the soil than is hydrated lime.

TABLE 12. CONVERSION FACTORS FOR LIMING MATERIALS

Given, per cent as	To find, per cent as	Multiply by
Calcium oxide, CaO	Calcium carbonate, $CaCO_3$	1 784
Calcium carbonate, $CaCO_3$	Calcium oxide, CaO	0 560
Magnesium oxide, MgO	Magnesium carbonate, $MgCO_3$	2 091
Magnesium carbonate, $MgCO_3$	Magnesium oxide, MgO	0 478
Magnesium oxide, MgO	Calcium oxide, CaO equivalent	1 390
Magnesium carbonate, $MgCO_3$	Calcium oxide, CaO equivalent	0 664
Magnesium carbonate, $MgCO_3$	Calcium carbonate, $CaCO_3$ equivalent	1 186

EXAMPLE: Compare a high-calcium hydrate that has 68 per cent of CaO with a high-magnesium hydrate that contains 38 per cent CaO and 30 per cent MgO.

High-magnesium hydrate	38 per cent CaO
Magnesium oxide 30 × 1.39	41 7 per cent CaO equivalent
Total	79 7 per cent CaO equivalent
High-calcium hydrate	68 0 per cent CaO
Superiority of high-magnesium hydrate	11.7 per cent CaO equivalent

Similarly any comparison may be made by using the right factor from Table 12.

The conversion factors in Table 12 may be used for comparing the values of different liming materials. Suitable fineness of limestones is assumed, of course.

These factors are based on chemical equivalents of calcium and magnesium. Because of its slower action in soils, however, some doubt exists whether magnesium carbonate corrects any more acidity in a year or two than does calcium carbonate. Some workers prefer to use the total carbonates (the sum of the percentages of calcium carbonate and of magnesium carbonate) rather than the calcium carbonate equivalent of high-magnesium limestones. For the clover crop for which such limestones are used, total carbonates probably give the best evaluation of high-magnesium limestones in comparison with ordinary calcium limestones.

Magnesium, however, is an essential plant-food element, and some soils lack enough magnesium for all crops. In such a situation, the use of high-magnesium or dolomitic limestone is desirable. Alternating the application of high-magnesium with high-calcium limestones is good practice if there is the slightest possibility of a shortage of magnesium as plant food. There is no objection to the use of dolomitic liming materials in humid areas. Whatever liming material supplies neutralizing power for least outlay is the best one to use. This is based on the assumption of suitable fineness of all the limestones that are under comparison. High-grade dolomitic hydrates are concentrated liming materials.

Selecting the Form of Lime to Use. Several points need consideration in selecting the form of lime to use. The cost per acre of lime hauled to the farm and spread on the land, the lime requirement of the crop, how quickly and how completely the acidity must be corrected, the profit that may be expected from liming, and the indirect effects of liming all need to be considered. The form of lime that corrects most acidity per dollar invested during the year it is put on is suitable for feed crops. For crops that have a high lime requirement or are sensitive to acidity, it may be best to use at least some of the quick-acting hydrate even though it usually costs more than does limestone. For a crop like cauliflower, quick reduction in pH and complete neutralization of acidity is essential; consequently hydrate or quicklime is selected. For crops that produce high returns, the most convenient suitable form may be used without much regard to cost. The profit expected from liming must always be considered.

If expected returns are low, the least expensive liming material must be used. Generally, on the basis of these considerations, limestone of a moderate degree of fineness is selected for feed crops.

5. Correcting Soil Acidity

When mixed with soils, lime releases calcium ions to the soil solution. These ions exchange places with H^+ ions in the colloidal clay. The H^+ ions combine with OH^- ions to form water and, therefore, no longer affect the reaction of the soil. In time the calcium ions displace the hydrogen ions in the clay so that the soil, for a time at least, is alkaline. In time, however, through the action of carbon dioxide, H^+ ions form again. They are very active and displace Ca^{++} ions from the clay and finally dominate the soil again. The Ca^{++} ions may unite with nitrate, NO_3^-, or HCO_3^{--} ions, and the $Ca(NO_3)_2$ may be used by plants, or both $Ca(NO_3)_2$ and $Ca(HCO_3)_2$ may be leached out of the soil and lost. When the free calcium carbonate is used up, H^+ ions in time again dominate the soil and it is acid once more. For this reason, moderately limed soils become acid and need to be limed again in 4 or 5 years. Thus, the tug of war goes on between soil acidity and applications of lime.

Using Lime to Increase Yields. Because soil conditions vary greatly, as do also the lime requirements of plants, no statement can be made as to the increase in yield that lime can produce. All the different factors must be known before any estimate of the effectiveness of liming can be made. The tabulation, Relative Response of Plants to Conditions That Accompany Varying Degrees of Acidity (page 170) is of real service. From this information it is clear that liming benefits some crops and harms others.

It has been found that liming improves the effectiveness of fertilizers on highly acid soils. Without liming on such soils, corn, oats, and wheat may make small yields even when fertilized. Liming and fertilizing highly acid soils greatly increases yields. In some instances the yield from 1 acre of acid soil that was limed and fertilized is larger than that from 2 acres, one of which was limed and the other fertilized. On these soils lime improves the effectiveness of the fertilizer.

Liming often more than doubles the yield of clover, lespedeza, alfalfa, and other legumes on silt loam soils that have an acidity of about pH 5. The same holds for timothy following a legume (Fig.

107). This increase in timothy is more because of the nitrogen fixed and left in the soil by the clover than it is because of the sensitiveness of timothy to soil acidity.

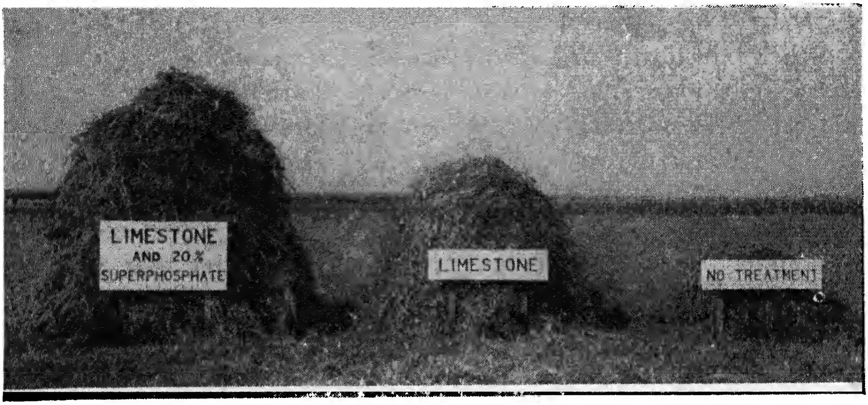


FIG. 107. Effect of liming alfalfa in Oklahoma. Limestone increased the average yield (1938–1943 inclusive) from 1,720 pounds of hay an acre to 2,450 pounds; 2 tons of limestone put on in 1936. Superphosphate (200 pounds 20 per cent an acre annually) further increased the yield to 5,300 pounds an acre. Lime could not exert its full effect until phosphorus was applied. (*H. J. Harper, Oklahoma Agricultural Experiment Station.*)

Determining How Much Lime to Use. After deciding on the kind of lime to buy it is necessary to determine how much to use to the acre. The kind of lime, or its neutralizing power, the sensitiveness of the crop, the number of years between limings, and the acidity of the soil determine the rate of application. The kind of lime that is most economical was discussed in the preceding section. The sensitiveness of crops to acidity or their relative lime requirements are shown in the tabulation on page 170. The number of years is easily determined in regular rotations, such as the widely used 4-year one in the East: (1) cultivated crop, (2) grain, (3) clover, (4) grass for hay. Even in this rotation, however, the grass may be cut for hay or it may be pastured a year or two in addition. The point is that lime is lost at a rate equivalent to 300 or 400 pounds of good, finely ground limestone an acre a year. After liming sufficiently for a desired sensitive crop, the equivalent of 1 ton of high-grade, finely ground limestone an acre once every 4 to 6 years is sufficient. The condition of the soil is the final point, and that is determined by testing it.

Collecting Soil Samples. The results of soil testing are of greatest value if the samples tested truly represent the garden, field, or farm under consideration. In order to have a representative sample, dig a hole from 6 to 7 inches deep and straighten one side with the spade. Cut a V-shaped notch in the straight side, being careful to get the same quantity of soil from the upper, the middle, and the lower parts of this surface soil. Get similar samples from six or eight places in order that the entire soil may be well represented. Mix the soil thoroughly and take a pint as a sample. Put the sample in a clean container or wrap it in heavy paper. (Glass jars are undesirable as they are likely to be broken in shipping.) Mark this sample "surface soil." A wood auger 1 or 2 inches in diameter is a better implement for sampling, and with it the work can be done in less time.

If there are distinctly different types of soil, such as a light-colored, sandy ridge with dark-colored, heavy soil in the same field, sample each type, as they are likely to have different lime requirements and to need varied treatment.

Send the package, with your name and address, to your agricultural college or county agent. Give the cropping system followed for the past 2 or 3 years, and state the quantity of manure and fertilizer used and the crops to which they were applied. You should give also the rotation you plan to follow during the next few years.

Testing Soils for Lime Requirement. Numerous soil tests for lime requirement have been devised. The most widely used at the present time are those that determine, or from which the operator can estimate, the pH of the soil. The direct determination of pH with the glass electrode is the most accurate. A series of indicators, each of which covers a part of the pH range, gives satisfactory pH readings. Another type of method is that in which a mixture of indicators is used. Each indicator gives its color at the corresponding pH of the soil. A different type is the Comber test, in which the solubility of iron is the indication of acidity. As shown earlier, iron compounds in the soil are more soluble at high than at low acidity. Potassium thiocyanate is the indicator solution. It turns red if the soil is moderately to highly acid, faintly pink at slight acidity, and remains colorless if the soil is neutral or alkaline. With care to use comparable quantities of soil and testing solution, test tubes of similar diameter, and careful operation, sufficiently accurate lime-requirement

determinations for feed crops can be made. Color charts or standard soils[3] may be used for purposes of comparison.

All of these methods are more or less indirect, and experience is helpful in operation and in making comparisons. Experienced assistance is desirable for making the interpretation and deciding how much of which lime to use for a specific crop or rotation of crops.

Applying the Right Amount of Lime per Acre. Sometimes lime is applied in excess of the quantity that is indicated by the test or, perhaps, without testing. Sometimes gardens and lawns are heavily limed year after year in the mistaken idea that they need it. Many samples of soil from gardens and lawns that had been overlimed for a period of years have been tested by the writer. Like farm soils, garden and lawn soils should be limed according to the requirements of the plants that are being grown.

In some sections, heavy applications (3 to 5 tons or more of coarse limestone to the acre) are made at long intervals. From what has been said earlier it is clear that certain plant-food elements may be rendered insoluble by lime. Phosphorus, iron, manganese, and zinc may be rendered unavailable to plants at least for a time. In places, plants become chlorotic; that is, the leaves turn a pale green or nearly white. They are definitely suffering from an abnormal condition. They are unable to obtain these essential elements in sufficient quantity. Yields, of course, are reduced by thus overliming. It should be understood that this difficulty is not encountered very frequently, yet a word of caution is desirable.

Avoid heavy liming for acid-loving plants. Such plants are adjusted to large amounts of the elements that are soluble in highly acid soils. Without them they cannot make normal growth.

Testing for lime requirement of crops can be done at slight expense. It is unwise, therefore, to lime blindly with possible injury to crops as the result. After a liming system has been established, particularly for a rotation of feed crops, little testing is needed. For vegetables, flowers, and greenhouse crops, however, it is safest to test often enough to lime to the best advantage for specific crops. *Light* or *fractional* liming has been tried with good results. Applications of limestones are made in direct contact with the seed of the crop to be

[3] Gustafson, A. F., The Use of Standard Soils with the Potassium Thiocyanate Test for Estimating Lime Requirement of Soils. *Journal of the American Society of Agronomy*, Vol. 16, pp. 772–776, 1924.

grown. With this method it is best to use the slow-acting limestone rather than the more rapid-acting burned or hydrated limes. Sow limestone and seed with a grain drill. The seed and limestone go down the same tube and are deposited close together in the soil. Liming in furrows farther apart also has been tried with apparently good results. If plant roots can make contact with "centers of alkalinity" they seem to thrive. This may be expected to be true, especially if the soil is deficient in calcium or magnesium as plant food.

Deciding on Time for Liming. Burned and hydrated limes applied and mixed with moist soils correct acidity in a few days. In contrast, limestones, particularly the coarser-ground ones, are slow in their action. Limestone should be well mixed with the soil because it acts by contact with the moist soil. The more thoroughly it is mixed, therefore, the more quickly and completely it corrects the acidity. There is far more contact between the lime and the soil if the stone is finely ground than if it is coarsely ground. Each particle of limestone is a center of alkalinity from which plant roots may obtain calcium, and which corrects acidity. There is essentially no movement of lime in soils except a very slow downward leaching of it as bicarbonate.

For sensitive crops such as alfalfa, sweet clover, cauliflower, and even red clover, put on limestone and mix it with the soil several months before seeding these crops. Wherever the lime requirement for alfalfa is 1½ tons an acre or more of finely ground limestone, apply one-half of the requirement for the preceding cultivated crop. During seedbed preparation and cultivation of the crop, the lime is mixed with the topsoil and acidity is being corrected. Put on the rest of the lime needed for alfalfa after plowing for alfalfa, and mix with the soil. This application is made to best advantage several months ahead of seeding the crop. Thus limed, the acidity should be corrected in time for the alfalfa to make good growth. If coarsely ground stone is used, advance application is even more necessary than with fine material.

After soils have been limed a number of times, any particles remaining are well mixed with the soil. Liming in the spring before seeding clover in the nurse crop then gives satisfactory growth. Also, the lime may be applied before planting the cultivated crop in a 4-year rotation of (1) cultivated crop, (2) grain, (3) clover, and (4) timothy. Another place for lime in this rotation is on the timothy

meadow after the crop has been harvested. The lime is mixed with the soil by plowing and by the subsequent tillage operations.

Alfalfa and clover have been used merely as representative of sensitive legumes; one is a perennial, the other a biennial. Alfalfa has a high and clover a medium lime requirement. Soybeans, white clover, cowpeas, and lespedeza have somewhat lower lime requirements. For most of these legumes. liming ahead of seeding gives fairly satisfactory results.

Choosing Ways of Applying Lime. In an earlier day and even now, in places, lump lime is slaked in piles in the field and spread by

Fig. 108. Horse-drawn spreader. Much lime has been put on for clover in the past with this type of outfit. (*L. B. Miller, Illinois Agricultural Experiment Station.*)

hand. This method, however, is not employed on fair-sized fields where machinery is available and can be used. Hand spreading of home-slaked hydrate with a shovel from a wagon or truck is done in connection with the burning of lime on the farm or nearby. Such spreading is very dusty, and therefore disagreeable for both men and horses.

Spreading limestone or hydrate on plowed land with a drill type of spreader has been practiced for a good many years (Fig. 108). This method, however, requires much hand loading and unloading of the bagged stone before it is spread on the land.

A more direct method that requires far less handwork has been introduced during the past few years. Haul the limestone in bulk

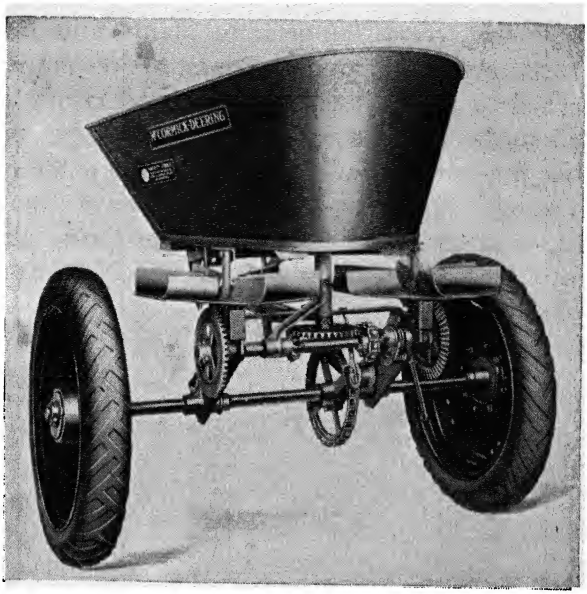


FIG. 109. The fan-type lime spreader. (*International Harvester Co.*)

FIG. 110. The fan-type lime spreader in action. This type of spreader may be used in hauling limestone direct from the quarry or the car and spreading it on the land without additional handling. Reducing the labor required increases the efficiency of producing crops. (*International Harvester Co.*)

in large trucks direct from the grinding plant to the field. Attach a spreader to the truck and put the limestone on the land without its being touched by human hand (Figs. 109 and 110). This method of spreading may be used on meadows any time after they are harvested. From July until snow covers the ground is the period available for spreading. Spreading lime at this time of year relieves the strain on help and spreading facilities in the spring ahead of oat-seeding time. This is especially true in the Northeast. Another

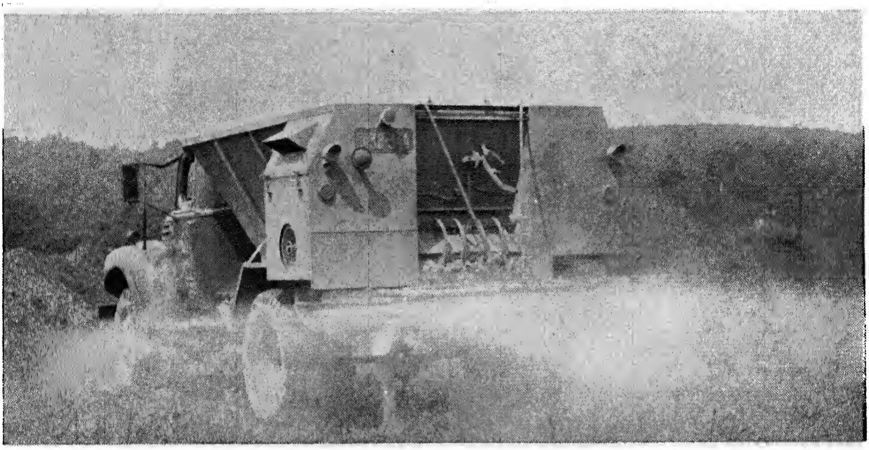


FIG. 111. A custom lime-spreading outfit in action. The limestone is hauled direct from the grinding plant or car in 5-ton loads. Moist limestone may be distributed in this way. A conveyer in the bottom of the truck box is operated from the truck wheels and delivers limestone in accord with the amount of land covered. The fans are operated by a gas engine, which is enclosed at the left. This is a very economical way of spreading limestone. (*Grange, League, Federation Exchange M. L. Dake.*)

type of spreading device is a worm feed built into the bottom of the truck (Fig. 111). The actual distribution is done with the endgate type of spreader. Although the limestone is not put on so uniformly as with the drill, it gives satisfactory results.

Limestone that is applied to meadowland ties up capital for 3 years or more until the milk check comes in or the beef cattle or sheep are marketed. Nevertheless, the convenience of this method and the great saving in labor makes it unusually attractive. There is some loss of lime by leaching during the 2 years before the clover crop is grown. The crop on the land, however, is benefited, and that offsets this loss of limestone.

6. Liming for Special Crops

Some plants such as flowers, ornamentals, and certain vegetables require high acidity; others require low acidity or a very narrow range in pH. Soils, moreover, vary in the quantity of lime required to produce the desired change in pH. Light, sandy soils are easily changed; heavy clays require much lime for small changes in pH, particularly in the range of acidity that is stronger than pH 5. The quantity of hydrated lime that is needed to change the pH of soils was determined by Sprague in New Jersey. His data are given in Table 13.

TABLE 13. POUNDS OF HYDRATED LIME NEEDED TO CORRECT SOIL ACIDITY*

Soil acidity	Hydrated Lime, pounds per 1,000 square feet			
	Light sandy soils	Medium sandy loam soils	Loam and silt loam soils	Clay loam soils
pH 4.0	60†	80	115	145
pH 4.5	55	75	105	135
pH 5.0	45	60	85	100
pH 5.5	35	45	65	80
pH 6.0‡	None	None	None	None

* SPRAGUE, H B, Liming Lawn Soils, *New Jersey Agricultural Experiment Station Circular* 362, p 4, 1936.

† Multiplying these amounts by 40 gives the approximate application needed for an acre

‡ Such slight acidity as pH 6 0 is not detrimental for the plants in question Applying 25 pounds of lime per 1,000 square feet, however, has proved beneficial on certain soils with a reaction of pH 6.0.

7. Growing Acid-loving Plants

Many gardeners wish to grow acid-loving plants on soils whose acidity is too slight. Either of two plans may be followed. (1) Bring in soil of the right acidity to replace that which is unsuited for these plants. (2) Treat the soil with acidifying materials. Aluminum sulphate, iron sulphate, or sulphur serve this purpose. These materials work best if they are mixed with from 6 to 9 inches of the surface soil and acid organic matter.

In Table 14 are given the quantities of finely powdered suphur that are needed for soils of different degrees of acidity.

TABLE 14. QUANTITIES OF SULPHUR NEEDED TO CHANGE THE pH OF SOILS*

Original Acidity of Soil	Sulphur, per 100 Square Feet
Moderate acidity (pH 5.5 to 6.0)	2 pounds
Slight acidity (pH 6.0 to 7.0)	4 pounds
Slight alkalinity (pH 7.0 to 7.5)	7 pounds
Higher alkalinity unsuitable for acid-loving plants	

* Fertilizer recommendations for New York, *Cornell Experiment Bulletin* 281, p 34, 1939.

After about 2 months, test the soil. If the pH is still above 5.5, make a second application of sulphur. It helps greatly to cover the surface of the soil under the plants with acid organic matter such as peat moss, rotted sawdust, or rotted oak leaves or pine needles. Heavy soils may use even larger quantities of sulphur to advantage along with acid organic matter mixed with the soil.

8. Liming to Control Plant Diseases

Some plant diseases are aggravated by liming; others are controlled by it. The organism that causes clubroot on turnips, cabbage, cauliflower, brussels sprouts, kale, and broccoli thrives in acid soils. An application of hydrate or burned lime that brings the reaction of the soil up to pH 7, or thereabouts, controls this disease.

Temporary deficiency disorders such as those resulting from a lack of available iron and manganese and those from lack of boron may be caused by extremely heavy liming with hydrate at one time, such as is done for cauliflower. The fungus that causes take-all of wheat thrives in acid soils and is controlled by liming.

Potato scab, in contrast, is serious in certain mineral soils in the zone from pH 5.6 to slightly above pH 7.1. A pH of 5.3 is desirable for potatoes, but there are some exceptions on muck soils. At both higher acidity and higher alkalinity there is less scab. If the pH goes too low, however, the yield of potatoes is greatly reduced. Turning under green material lowers the percentage of scabby potatoes at all pH levels. Accurate testing with the electrical method and treating according to test is necessary for the production of clean potatoes on soils of only slight acidity.

SUMMARY

1. Soil acidity comes about from the loss of lime and similar materials and the constant formation of acid in soils during warm weather. Lime equivalent to that in about 300 or 400 pounds an acre of high-grade limestone is lost annually from northern humid-region soils.

2. Carbon dioxide, which produces acid in soils, comes to the soil in rain, and large quantities of it form during the decay of organic matter in the soil. This acid dissolves lime and other basic materials that leach out of the soil and eventually makes soils acid.

3. Soils contain *active* and *reserve* acidity. Active acidity is in the soil moisture in relatively small total amounts. Reserve acidity is held in the clay part of the soil. Strongly acid soils contain many times more reserve than active acidity.

4. Some crops are sensitive to soil acidity, others tolerate moderate acidity, and some plants thrive only in strongly acid soils. It is the acid-sensitive crops whose yields are increased most by liming on strongly acid soils. Liming soils to which acid-loving plants are adapted may injure them.

5. The availability of phosphorus is low in acid soils. Liming strongly acid soils helps to hold phosphorus in forms available to crops.

6. There are three forms of lime: carbonate or limestone, burned lime, and hydrated lime. Limestone is most widely used. Blast-furnace slag and wood ashes also possess value as liming materials. Gypsum and common salt probably have little if any value for correcting soil acidity.

7. Burned lime is most concentrated, hydrate is next, and limestone least concentrated. Their speed of action is in the same order; limestone and slag are slowest in their action. Nevertheless, because of the slight cost of preparing limestone for use on the soil, many times as large a tonnage of limestone as of burned and hydrated limes combined is used on the soil.

8. Compare the different limes on the basis of the cost of putting on enough to the acre to produce the desired crop. For most feed crops, it is essential to use the lime that costs least for the production of clover, alfalfa, or any other sensitive crop. This is because these crops cannot bear high costs of production. For high-return crops, however, the higher-cost materials may be used.

9. There is no objection to magnesium in limestones for use on the soil. In fact, some soils are becoming deficient in magnesium as plant food; the addition of a magnesium-bearing limestone, therefore, may benefit certain crops.

10. Yields of clover, alfalfa, cabbage, cauliflower, corn, cotton, peanuts, and many vegetable and other crops on strongly acid soils are markedly increased by liming.

11. Determine how much lime to use to the acre by testing the soil or by having it tested. Do not use more lime than is needed because this is uneconomical and because some crops may be injured by overliming.

12. Test the soil to avoid overliming and to be sure that enough lime is being used for the crops that are grown.

13. Acid-loving plants require special attention on slightly acid or neutral

soils. Acidify the soil; then test after 6 months to learn whether more of the acidifying agent is needed.

14. You may apply limestone to any soil that does not have a crop on it, at any time that the soil is firm enough and is not too deeply covered with snow. Putting lime on meadows that are to be plowed for a cultivated crop the following year is good practice.

15. Many types of satisfactory spreaders are used for applying lime. The type used on a truck without the necessity of shoveling bulk limestone is most economical.

16. Liming helps to control certain crop diseases such as scab of wheat and clubroot (finger-and-toe in Europe) on cole (cabbage family) crops. On certain soils the use of lime encourages potato scab.

7. Managing Alkali Soils

SOLUBLE materials developed in soils during their formation and also develop in the continuing processes of weathering. In humid soils rain water dissolves and carries away much of these soluble materials. In the drier areas, however, there is not enough rain to leach out these materials and they accumulate in the soil as harmful salts, commonly called alkali.

Managing alkali soils will be discussed under the following headings:

1. Recognizing the Causes and Nature of Alkali in Semiarid Regions
2. Determining Relationships between Alkali and Soils
3. Reclaiming Alkali Soils in Dry Areas
4. Recognizing the Causes and Nature of Alkali in Humid Areas
5. Improving Humid Alkali Soils

1. Recognizing the Causes and Nature of Alkali in Semiarid Regions

Regions that receive less than 20 inches of average annual precipitation are classified as semiarid and arid. The semiarid lands include those that receive between 10 and 20 inches, and the arid, less than 10 inches of water as rain and snow, on the average, annually. In certain sections there are distinct wet and dry seasons.

Because of a shortage of rainfall in semiarid and arid regions, *salts* accumulate in the soil. In humid areas these soluble materials are leached out in drainage water. Some downward movement of salts occurs after rains, but salts near the surface tend to return to it, in a measure, during later dry periods. In this manner, light rains may bring some salts to the surface. Much of these soluble salts are in or on the surface of the soil and constitute the common *alkali* of these dry regions. These soluble salts are most commonly found in basins or depressed areas that have poor drainage. They accumulate also in practically level areas, especially if the surface and subsoil are of a clayey nature. Sandy soils also may contain alkali, under conditions

that favor its collection. Even in free-draining sandy soils the rainfall is not sufficient to wash out the soluble salts. In addition, alkali often accumulates in low-lying spots as a result of seepage water from higher lands.

A study of soils in the drier part of the globe reveals that many of them contain alkali. The terms, *saline*, *alkaline*, and *alkali* are used in describing these soils. *Saline* soils contain relatively large amounts of neutral or nonalkaline salts such as chlorides and sulphates. These soils have a pH of 7 or less. *Alkaline* soils are those that contain a high percentage of such alkaline salts as *sodium carbonate*. *Alkali* soils are those that contain enough of any soluble salts to injure crop plants. Both the alkaline and the alkali soils are alkaline in reaction, with pH 7 or higher.

Farmers in the drier areas commonly irrigate their lands to produce higher yields of a wide variety of crops. The water used for irrigation generally has a higher percentage of soluble salts than does ordinary rain water. There is also intense evaporation of water in these dry areas. Consequently, the salts in the irrigation water accumulate in the surface soil.

Sometimes excessive amounts of water are used and the water table is raised to a zone near the surface. This is a favorable condition for rapid upward movement of salts and for their concentration in the topsoil. Seepage from leaky irrigation ditches has similarly raised the water table in low places near them. High water table results from overirrigation and leaky canals. Both conditions follow poor management and lead to the accumulation of harmful alkali.

Determining Alkali Salts Harmful to Plants. The principal compounds in the soluble salts of alkali soils are carbonate, bicarbonate, chloride, and sulphate of sodium. The sodium chloride, or common table salt, is familiar to all. The alkaline condition, higher than pH 7, is credited to sodium hydroxide (sodium, Na, combined with OH to form NaOH). Calcium and magnesium, along with some other compounds, are often present in higher percentages than the sodium salts. The calcium and magnesium compounds, however, seldom injure crops.

The terms "white alkali" and "black alkali" have long been used to designate two very different conditions in dry-land or irrigated soils. A white alkali soil is a saline one that contains more than about 0.2 per cent of soluble salts, but it is not strongly alkaline. A black alkali

soil contains alkali salts. These usually include sodium carbonate in harmful quantities. Black alkali soils have a pH of 8.5, or stronger alkalinity. Sodium salts dissolve the humic organic matter and this gives the black color. It is from this color that the designation "black alkali" comes.

Observing Effect of Alkali on Crops. The moisture in alkali soils contains large percentages of salts in solution. Injury to plants may be caused by too great concentration of salts even though, of themselves, they are harmless. In fact, many of the salts in alkali soils are harmless in the concentration usually present in the moisture of humid soils. Even common salt is harmful in strong concentrations. This is clear when it is remembered that salt is often used to kill weeds. In contrast, plants thrive on soils whose moisture is an extremely dilute solution. The alkali sometimes eats or corrodes the upper part of the roots of plants. Black alkali is most harmful to them. Sodium chloride is less injurious and sodium sulphate still less harmful than black alkali. The plants that grow on irrigated alkali soils are generally spotted and stunted, and the leaves yellow, if the alkali is strong.

Observing Plant Tolerance of Alkali. In virgin soils the presence of alkali is often indicated by occurence of plants that tolerate alkali. Some wild plants are sensitive to it; others are alkali-enduring or tolerant of alkali. Greasewood, Australian saltbushes, saltwort, salt grass, bushy samphire, Bermuda grass, tussock grass, the common redtop of the Middle West and the East, rye, and barley are generally fairly tolerant of alkali. While it is young, alfalfa is easily injured by alkali. It becomes more tolerant with age or is damaged less as the plants become older. Sweet clover thrives in alkali soils. Sugar beets endure alkali fairly well, but most fruit trees are damaged by even a low concentration of alkali salts. Citrus and walnuts are sensitive and easily injured by alkali.

2. Determining Relationships between Alkali and Soils

The texture, or the size of soil particles, affects the toxicity, or poisonous effects, of alkali on crops. Crops on coarse-textured soils, like sands, are injured more by a given amount of alkali than are the same crops on fine-textured silty or clayey soils. Crops also vary in their tolerance of alkali. It is hardly possible, therefore, to name any

specific figure that represents an injurious concentration of salts in alkali soils.

In mapping alkali soils, many soil tests for alkali are made. A separate alkali map shows the location of the samples, the concentration of alkali in the surface foot, and the average concentration to a depth of 6 feet. On the map, *A* means concentrations of alkali that are likely to be injurious to crops; *M* means moderate concentration; *S*, slight concentration; *F* means free of alkali. Where a general area is not affected, alkali spots are shown on the map with symbols. A separate alkali map is not required.

The agricultural value of alkali soils may be rated, but the location of alkali in the soil profile is important. Consider two soils that are similar except for differences in alkali content. Areas that contain much alkali may be rated at less than 25 per cent and those that are alkali-free at 100 per cent. Soil areas that are considered as having injurious alkali contain on the average throughout the profile from 1 to 3 per cent of white alkali. Much smaller percentages of black alkali produce serious damage to crops. Alkali-free soils have less than 0.2 per cent of white alkali, but much less than 0.2 per cent of black alkali. It is considered that the alkali is uniformly distributed and not more concentrated in one zone than in another.

White alkali does not usually puddle the soil or destroy its structure. Flooding white alkali areas to reduce the alkali concentration and then draining the area may produce poor physical condition. Any considerable concentration of black alkali, however, destroys the granular structure of the soil and reduces the percolation rate of water.

3. Reclaiming Alkali Soils in Dry Areas

Two general methods are used for reclaiming alkali soils: (1) removing the alkali salts and (2) reducing the harmful effects of alkali.

Removing the Alkali Salts. Irrigation water that carries large quantities of salts, even if used lightly, soon causes an accumulation of these salts in the upper part of the soil. Here it is that the plant roots are located; hence, the salts injure the crop. Heavy irrigation once a year dissolves the salts and carries them into the drainage system or down beyond the reach of plant roots. Not only must the farmer know the salt content of irrigation water, but he must know the salts that are present. The reason is that some salts are so much more injurious than others.

Compounds of calcium in irrigation water are beneficial because they improve the physical condition of the soil and drainage through it. Calcium in the water is particularly helpful if the soil contains harmful sodium. If the water carries much sodium the soil becomes puddled and water goes into it less freely. This condition is improved by putting on calcium or sulphur. These materials break up the puddled condition and restore a mellow, granular condition.

The location of the water table is important. It should not be less than 6 feet below the surface in most soils. The depth to the water table, therefore, should be determined several times a year.

Some crops require deep soils. The English walnut is one of them. It needs a soil at least 20 feet deep. In other words, for walnuts, the water table must be at least that distance below the surface. In some sections, however, overirrigation has raised the water table to within 6 feet of the surface.

Many areas in the irrigated sections of the United States were highly productive when water was first put on the land. Within 25 years, however, alkali has become so strong that little except poor pasture is produced. *When concentration of alkali first appears, check its accumulation.*

High water table and alkali go hand in hand. The cause of a high water table calls for attention. Alkali spots sometimes lie near the base of a slope that is the source of the water. If so, provide a deep ditch to collect and carry away the excess water. This ditch prevents the continuation of the high water table and the rise of the alkali salts into the surface soil or the root zone of crops. If a leaking irrigation canal is supplying the water, waterproof the bottom of it to prevent further damage.

The water can be removed by means of open ditches or by tile. Under some conditions the water may be pumped out to prevent injury to crops on the lower land. By thus removing the excess water, the alkali salts in it are prevented from rising to the surface. It is in the surface or root zone that alkali salts may injure crops. In fine-textured or slow-draining soils it is difficult to remove water in this way. Moreover, it is costly because the lines of tile must be placed close together to lower the water table in a reasonable length of time.

It is good practice to wet the soil with irrigation water to the bottom of the root zone and no deeper. Unnecessary depth of irriga-

tion is costly. Determine the depth of penetration with a soil auger or soil tube. This can be done some days after the water is applied. Six feet is a usual depth, but well-established alfalfa or walnut orchards require a deeper moist zone.

Injury by white alkali can usually be controlled by flooding and draining away the excess water. Such drainage water carries dissolved white alkali out of the root zone. Calcium salts in the soil or the irrigation water help in ridding the soil of excessive quantities of these harmful salts. Black alkali, in contrast, requires treatment.

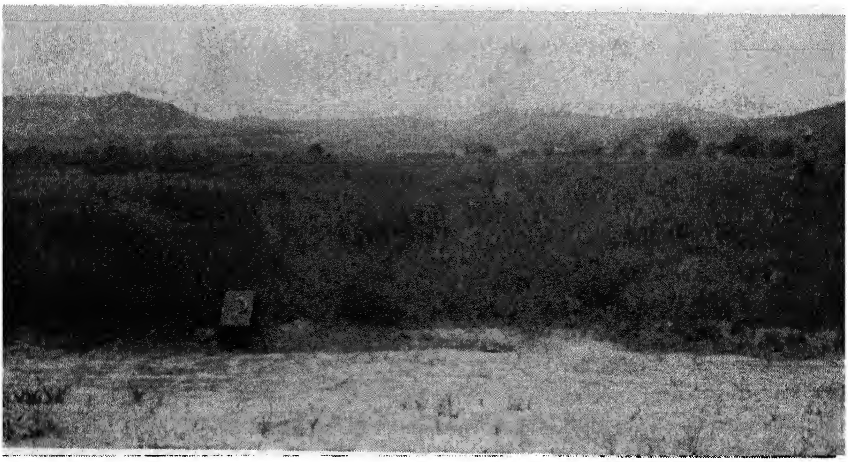


Fig. 112. Effect of sulphur on alkali land in Oregon. The bare soil in the foreground received no sulphur. In the background, 300 pounds of sulphur and barnyard manure were applied. After 2 or 3 years, a good stand of alfalfa was established and produced from 5 to 6 tons of hay an acre a year. (*W. L. Powers, Oregon Agricultural Experiment Station.*)

The application of sulphur, gypsum, or alum improves the drainage and shortens the time of reclamation (Fig. 112).

The quantity of sulphur, gypsum, or alum to use varies with the concentration of black alkali and with the soil. High concentration requires a large amount of these treatments. The soil governs the rate of drainage through it. The presence of black alkali requires the use of larger quantities of gypsum, alum, and sulphur on heavy, fine-textured soils than light, coarse-textured ones. Clay layers were deflocculated by the black alkali, and large amounts of treatment are needed to improve granulation and rapidity of drainage. Coarse-textured layers drain rapidly with any treatment because they have

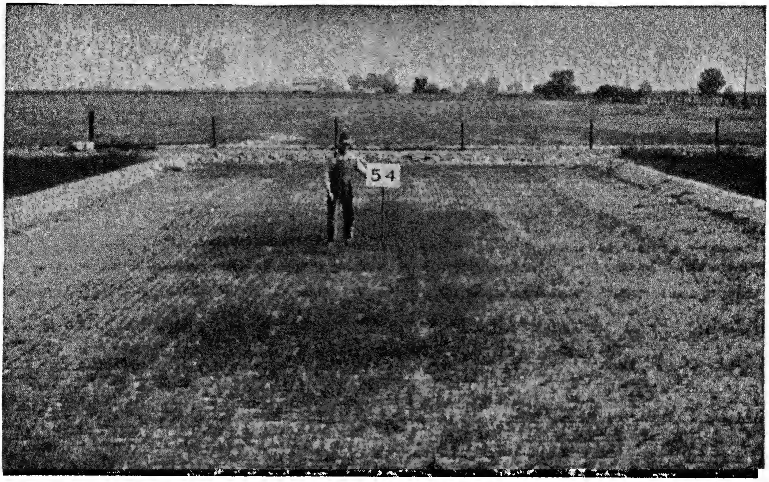


FIG. 113. Alfalfa failure on black-alkali soil in California. In spite of flooding and draining, alfalfa failed. Most of the alfalfa plants died soon after they were photographed. (*E. E. Thomas, California Agricultural Experiment Station.*)

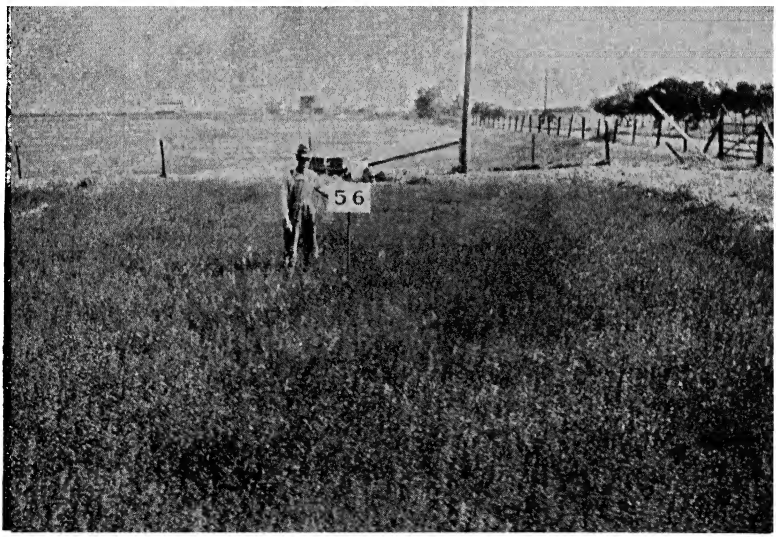


FIG. 114. Alfalfa on black-alkali soil after treatment with sulphur. Sulphur was applied in July, 1927, the soil being irrigated and cultivated the rest of the year. Hubam sweet clover was sown the next spring and plowed down in September. Alfalfa was sown in February, 1929. This stand of alfalfa was photographed on May 15, 1929. Comparison with Fig. 113 indicates the effectiveness of sulphur on this soil. (*E. E. Thomas, California Agricultural Experiment Station.*)

not been puddled. As much as 10 tons or more of gypsum to the acre have been used on experimental areas and the soil flooded and drained before good crops could be grown. One thousand pounds of sulphur an acre on some soils have produced marked improvement (Figs. 113 and 114). This heavy treatment makes reclamation of such soils expensive.

Soil organisms change the sulphur to acid, which combines with and neutralizes the black alkali. Because this work of organisms takes time, it may be several months before real improvement is achieved. Mixing the oxidizing organism with the sulphur may give quicker improvement in black alkali soils. Sulphur increases the amount of soluble calcium in the soil, and this improves its physical condition and the drainage.

The cost of treatment with these chemicals varies considerably in different sections. Kelley[1] obtained good effects at Fresno, California, from the use of ½ ton of sulphur. Larger quantities were not more effective. Alum and gypsum also produced good effects, but they were more expensive.

Reducing the Harmful Effects of Alkali. Crops have been grown successfully on land that originally contained alkali in harmful quantities. By irrigating, the soil was kept moist and the alkali dilute so that crops were produced in spite of the high original alkali content. Allowing soils to dry out concentrates the alkali salts in the surface soil. Practicing light irrigation, therefore, is not recommended.

The physical condition of the soil can be improved by using farm manure and by growing Bermuda grass and other pasture grasses. Carbon dioxide is given off by plant roots and in the decay of manure. The carbon dioxide brings calcium into solution, and the soluble calcium in turn reacts with the black alkali. The black alkali can then be more readily washed out of the soil.

Green-manure crops are helpful. *Sesbania*, which is a leguminous crop, tolerates alkali. This plant has been used as a green-manure crop, and it aids greatly in the growth of crops under irrigation.

4. Recognizing the Causes and Nature of Alkali in Humid Areas

In comparison with the acreage of alkali[2] soils in irrigated regions the acreage of alkali soils in the humid region of this country is small.

[1] KELLEY, W. P., The Reclamation of Alkali Soils, *California Agricultural Experiment Station Bulletin* 617, 1937.

[2] Not all of the so-called alkali soil in humid areas is really alkaline; some of it is slightly acid The growth of crops is abnormal, and fine distinctions are not always made.

The alkali problem in humid areas is not particularly acute—nothing like that in the irrigated areas. In the humid regions of this country, alkali soils are confined to swamps or shallow-lake bottoms and spots where seepage water has brought soluble materials to the surface. By evaporation of the water, the soluble salts have accumulated in the surface soil, and there they remain in spite of leaching by rains.

These alkali spots occur as small, unproductive areas in otherwise productive soils. In some old shallow lakes like those in central Illinois, areas of 1 square mile or more are found. Some of this soil is extremely loose and friable and of a dead-gray color. This is in distinct contrast with the usual black color of swampy land in that section. The numerous whole snail shells and fragments help to give the soil its grayish color. Corn fails completely on some of these spots. On others the plants are abnormal in color, height, and width of leaves. The plants are compressed, the internodes are short, and the leaves may have reddish streaks and are wider than usual.

As previously indicated, humid alkali is found in swamps, shallow, old, glacial lakes, and ponds. Some of these wet areas were more or less drained by nature; others have been reclaimed by large-scale drainage operations. These include big main ditches, or canals as they are called in the Everglades, lateral ditches, and extensive tile drainage systems as well.

The water of the swamps contained a lot of salts that remained in the soil when it was drained.[3] Swampland is nearly level and has low spots or pockets. Little surface runoff could take place to remove the salts. Evaporation took place and enriched the salt content of the surface soil. Often this forms a white incrustation, particularly after rains.

The proportions of the different salts present are rather variable. The composition of the alkali also varies from place to place. Calcium and magnesium carbonates and bicarbonates often form a large part of the alkali. Much nitrate and sulfates are also found. Sodium is found in humid alkali, but in smaller proportions than in arid alkali. Because of these differences in the alkali salts that are present, any one treatment cannot improve all humid alkali soils. Much of the damage to crops is believed to be caused by the salts of magnesium.

[3] Stevenson, W. H., P. E. Brown, and J. L. Boatman, The Management of Peat and Alkali Soils in Iowa, *Iowa Agricultural Experiment Station Bulletin* 266, pp. 99–100, 1937.

5. Improving Humid Alkali Soils

Four ways of improvement are suggested: (1) plowing in fresh, green organic matter; (2) using farm manure; (3) drainage; and (4) using potassium salts and, if needed, phosphorus.

Growing rye, oats, and other grains and grasses, and sweet clover and other legumes and plowing them under while they are green increases crop yields. The rotting of green manures helps to remove the soluble salts. This is accomplished by improving the granulation of heavy soils and, as a consequence, permitting more rapid downward movement of water than without such addition of organic matter. Crops have the benefit not only of improved drainage but also of the removal of harmful salts. Moreover, the green material appears to protect crop plants from the effects of the harmful materials.

The use of farm manure also helps crops on humid alkali soils. Manure is particularly helpful because it contains so many of the elements that the crops need. Farm manures are discussed in Chap. 9. On soils that are high in soluble calcium compounds, some of the needs of the crop may be rendered unavailable. Crops suffer, therefore, because they cannot obtain what they require. Swamp soils may have an excess of available nitrogen. Phosphorus may be lacking or unavailable in some areas and potassium may also be lacking or unavailable in other spots. Because manure contains these elements and because, in rotting, it may help to make them available to the crop, manure is particularly valuable to crops on these humid alkali soils. Coarse, strawy manure is most valuable if lack or unavailability of potash is the cause of poor crop growth. In addition, manure produces many of the benefits noted from green manures.

Thorough drainage both over the surface and through the soil is beneficial in all of the ordinary ways. Quick drainage removes the dissolved salts and thus takes them away from crop roots. This gives the roots a chance for more nearly normal growth, and larger yields of crops result.

Where potassium is not being obtained by the crop, it can readily be put on as potash fertilizer or in mixed fertilizer (Chap. 11). Probably the most concentrated potash salt is best, because more unusable salt material is left behind in the less concentrated ones (Fig. 115).

Manure, gypsum, and potassium salts were compared on peaty

alkali soil in Illinois for 5 years.[4] Manure was used at rates of 6 and 12 tons an acre, gypsum at 2, 4, 8, and 16 tons an acre, and manure at 6- and 12-ton rates. One hundred forty-eight pounds an acre of potassium sulphate were used.

Six tons of manure were equally as effective as 12 tons. The untreated check plot produced 13.5 bushels of shelled corn (56 pounds

FIG. 115. Potash increasing yield of corn on high-lime, or alkali, soil in Iowa. As an average of 31 comparisons in 16 counties, 100 pounds an acre of 50 per cent muriate of potash increased the yield of shelled corn 13 bushels an acre. These soils were rated as "highly alkaline." Potash produced a smaller increase in yield on soils of lower alkalinity. To be effective the potash must be put on each year. (*Iowa Agricultural Experiment Station.*)

to the bushel) to the acre as an average for 5 years. The average yield for the two rates of manuring was 46.6 bushels to the acre, an increase of 33 bushels for manure. The potash-treated plot produced 46.1 bushels to the acre as a 5-year average, or practically the same increase as was produced by manure. Both treatments produced an increase of about 33 bushels to the acre. This was an excellent increase for the treatment used, and under average conditions these treatments are very profitable. Gypsum reduced the yield of corn.

No phosphorus was used in the Illinois work except in manure.

[4] HOPKINS, C. G., J. E. READHIMER, and O. S. FISHER, Peaty Swamp Lands; Sand and Alkali Soils, *Illinois Agricultural Experiment Station Bulletin* 157, 1912.

In the work already mentioned in Iowa, reported by Stevenson, Brown, and Boatman, the peaty soils responded well to the use of phosphorus.

If the crop cannot get enough phosphorus from the soil, it may be applied in phosphorus-carrying fertilizer such as superphosphate or a high-phosphorus mixed fertilizer.

If no experimental work has been done in an area, trials can be made. Treat alternate strips with any of these materials or grow green-manure crops on every other strip. All other treatment, seeding, and management, of course, are held the same on all the land. By carefully harvesting exactly the same sizes of area in all treatments, and weighing the product, the effect of different treatments can be learned, at least in a general way. Because of the variableness of these humid alkali spots, farm tests may be of greater value than a small number of experimental plots.

SUMMARY

1. Alkali occurs in the soils of low-rainfall areas because there has not been enough rain to dissolve and leach out the soluble material. Soluble materials form in most soils, but they seldom accumulate in humid-region soils.

2. Too great a concentration of soluble material is harmful to plants, although they may tolerate small proportions of the same salts. Some salts are more harmful than others. Sodium salts, especially sodium carbonate, are particularly harmful to many crops. Calcium and magnesium compounds, in contrast, are not especially harmful to crops.

3. The terms "white" and "black" alkali have fairly definite meanings. White alkali soils are neutral, saline ones. Black alkali soils are usually distinctly alkaline. The color in black alkali soils results from the organic matter that is dissolved by the alkali.

4. Even harmless salts in great concentration are injurious to crops. This may be noted from the fact that common salt (sodium chloride) is often used to kill weeds on walks or drives. The alkali salts sometimes destroy the upper part of crop roots.

5. Alkali-tolerant plants on virgin soils may indicate the presence of alkali. Certain plants tolerate alkali; others are rated as alkali-enduring. Young alfalfa plants and fruit and nut trees are sensitive to alkali and are easily injured by it.

6. Crops on coarse-textured soils are easily hurt by alkali; those on heavy soils grow uninjured on a higher concentration of alkali.

7. In mapping soils in the drier regions, alkali maps are made. These maps show separately the areas that contain enough alkali to be distinctly injurious to crops and those that are free of alkali. Between these extremes, moderate and slight concentrations also are recognized.

8. Black alkali is more destructive of the tilth of soils than is white alkali. In fact, black alkali, in strong concentration, puddles heavy soils badly. Part of its injurious effect, no doubt, results from destroying the structure of the soil.

9. Alkali soils may be reclaimed by leaching out the alkali salts and by changing harmful salts to less harmful ones by means of soil treatment.

10. Salts may be removed by means of flooding and underdrainage. A water table near the surface usually leads to trouble. Black alkali soils are improved by treating them with gypsum, alum, or sulphur. The resulting salts are less harmful than black alkali.

11. Using manure and growing tolerant grasses improve the physical condition of the soil and reduce the harmful effects of alkali.

12. Alkali soils, so-called, occur in swampy places in humid areas. Such soils are often deficient in potash, and its use improves the growth of crops.

13. Thorough drainage, application of manure, and growing and mixing green manures and other organic matter with the soil help crops to overcome the harmful effects of humid-region alkali.

14. Conditions in these humid alkali soils vary. In Iowa the addition of phosphorus increased crop yields, but on such areas in Illinois no improvement resulted from putting on phosphorus.

15. Individual farm tests appear to be needed.

8. Keeping Up Organic Matter and Nitrogen in Soils

ALL productive soils contain organic matter. Some of it is new and active; some of it is old and relatively inactive. Soil *organic matter*, as the term is used here, refers to the nonliving material in the soil that came from either plants or animals. Soil organic matter is the food of many of the organisms in the soil. These organisms bring about decay, or rotting, of manures and the remains of plants that are on the surface or mixed with the soil. In the process of decay these organisms take from organic matter what they need as food for their growth. In doing this they liberate many simple products that serve our crop plants as food.

Keeping up organic matter and the nitrogen content of soils will be discussed under the following headings:

1. Comparing Sources of the Natural Organic Matter in Soils
2. Learning the Composition of Organic Matter
3. Distinguishing the Products of Decomposition of Organic Matter
4. Determining the Effects of Organic Matter on Soils
5. Classifying Losses of Organic Matter from Soils
6. Returning Organic Matter to Soils
7. Adding Nitrogen to Soils
8. Making Nitrogen in Organic Matter Available to Plants
9. Hastening the Decay of Leguminous and Nonleguminous Residues
10. Following the Nitrogen Cycle in Soils
11. Maintaining Active Organic Matter and Nitrogen in Soils

1. Comparing Sources of the Natural Organic Matter in Soils

The tiny green algae found in soils were probably among the first plants on the earth. Under certain conditions they obtain their own nitrogen from the air. Higher forms of plant life followed. Plants lived and died, and their substance was added to or worked into the

soil by earthworms, other worms, and many larger animals that burrowed in the soil. When animals die their bodies are added to the soil. In general, therefore, it may be stated that the natural or original supply of organic matter in soils came from decayed plants and animals. Most of it, however, came from plants.

In forested areas, the leaves and twigs fall to the ground, serve as food for soil organisms, and eventually become mixed with the soil. The trunks of trees fall to the ground, are overgrown by plants, decay, and are added to the soil. In prairie areas much the same process takes place. Each year's growth falls to the earth and is eventually mixed with it. It should be appreciated, however, that the aboveground growth of plants is pretty largely decayed and lost. Also, fires may destroy this part of the growth of native plants.

The roots of plants, trees, shrubs, vines, grasses, and other plants remain in the soil where they grew when the plants die. Here they remain moist, and air does not enter the soil freely. The roots, therefore, are preserved, and become the leading source of the organic matter originally in the soil.

Algae still add some organic matter to soils. The farmer returns the remains, leftovers, or residues from crops, certain crops grown for the purpose, and farm manures to the soil. Seldom, however, do these additions balance the losses that take place under active crop production.

The organic matter in mineral soils varies from almost none to about 8 or 10 per cent. Coarse, gravelly, and sandy soils have as little as only a fraction of 1 per cent. Sandy loams, loams, silt loams, clay loams, and clays, in general, contain increasing proportions of organic matter under similar conditions. Under swampy conditions or poor drainage, the organic matter is higher than in well-drained soils. A large share of well-drained mineral soils have from 2 to 5 per cent of organic matter on the basis of dry soil. A desirable percentage of organic matter for productive soils is about 4 per cent. The activity of organic matter is as important as the quantity in the soil. Organic soils contain as much as 75 to 80 per cent of organic matter.

2. Learning the Composition of Organic Matter

Fresh, green, succulent plant material contains, as a general average, 75 per cent water and 25 per cent dry matter. Of this dry matter, about 44 per cent is carbon, 40 per cent oxygen, 8 per cent

hydrogen, and 8 per cent ash, or mineral material. On the basis of the fresh, green weight of the plant material, these percentages are 11 per cent carbon, 10 per cent oxygen, 2 per cent hydrogen, and 2 per cent ash. The water, nitrogen, and mineral matter in plants come from the soil.

The percentages of carbon and nitrogen vary as between different kinds of plants and between different parts of the same plant. In the soil, differences in these percentages are found between plant materials newly turned under and old organic matter in the soil.

Leguminous plants are high in nitrogen content in comparison with such nonlegumes as grains, grasses, and woods. The leaves of alfalfa contain about 3.5 per cent nitrogen and the stems 1.6 per cent. The relationship between the amount or percentage of carbon and that of nitrogen in plant material or soils is referred to as the *carbon-nitrogen ratio.* It is found by dividing the number representing carbon by that representing nitrogen and is, therefore, the number of pounds or per cent of carbon present for each pound or per cent of nitrogen.[1]

Cereal straws have extremely wide C:N ratios or contain very large quantities of carbon in comparison with their content of nitrogen. C:N ratios of 80 to 90 and higher are common for cereal straws. Grains have much narrower ratios: oat grain, 23; wheat, 20; potatoes, 29; legumes, about 13 to 25; soil organic matter, 10 to 12. Protein has a C:N ratio of only 3. Soils and leguminous residues have narrow C:N ratios, with protein the extreme example of a narrow ratio. Cultivation tends to narrow the C:N ratio of old soils.

3. Distinguishing the Products of Decomposition of Organic Matter

Plant tissues are very complex in make-up. They are in no sense simple products. Their breakdown, which is brought about by the organisms in the soil, is no less complicated.

The decay of fresh organic matter takes place in steps. The starches, sugars, and water-soluble proteins are broken down first.

[1] Determine the carbon-nitrogen ratio thus: Rye straw contains 49.9 per cent carbon and 0.3 per cent nitrogen. Then $49.9 \div 0.3 = 166.3$. Rye straw contains 166.3 pounds of carbon for every pound of nitrogen—a wide C:N ratio. The C:N ratio may be found also by using pounds instead of per cent.

Rye straw contains 49.9 per cent carbon $\times$ 2,000 (pounds in a ton) or 998 pounds of carbon and 0.3 per cent nitrogen $\times$ 2,000 or 6 pounds of nitrogen. Then $998 \div 6 = 166.3$—the C:N ratio of rye straw.

A large group of materials is attacked next. The decay of oils, waxes, fats, resins, and lignin is very slow, because these materials are resistant to decay. Some of these products, especially *lignin*, become a part of *humus*, the part of old soil organic matter that is most resistant to decay.

The starches, sugars, and other constituents that are high in carbon break down into carbon dioxide and water. The nitrogen in proteins is changed to ammonia and this to nitrites and finally to nitrates. Plants take much of their nitrogen from the soil as nitrates.

Active decay, or rotting, of organic matter begins soon after it becomes mixed with moist soil. The organisms give off much carbon dioxide in the decay process, and this takes place while the number of organisms is increasing very rapidly. In fact, it is the increase in the number of the organisms that produces the carbon dioxide. Similarly, when the organic matter has been decayed, the number of organisms and the quantity of carbon dioxide given off drops rapidly. The more resistant materials, however, do not decay so rapidly; they stay in the soil much longer.

The dark-brown or black organic material in the soil is called *humus*. Humus resists decay under the conditions in which it was formed. Humus is relatively stable in soils, although it is subject to further breakdown by soil organisms. The decay of the organic matter that is added to the soil from time to time tends to keep up the supply of humus.

Humus is believed to be largely responsible for the favorable conditions in the soil that are usually credited to organic matter. Humus is of indefinite chemical composition, not like carbon dioxide, which is always the same—CO_2. Like the very finest clay particles, humus is colloidal; that is, it is jellylike in nature. It absorbs gases and holds plant foods much more effectively than does clay.

The dark-brown or black color of many soils is credited to their humus. Humus is the part of organic matter that brings about granulation and consequently improves the tilth of soils.

Soil organisms simplify organic materials that are added to the soil. Among these simplified products are carbon dioxide, sulphates, phosphates, ammonia, and nitrates. Some carbon dioxide may be used from the soil air, and all of the other simple products serve as food for crops. Thus are crops grown. Man and animals use parts of these products and the rest may go back into the soil. There they

serve as food for the life in the soil, and the organisms render them available for crops. These plant foods, therefore, are used over and over again.

4. Determining the Effects of Organic Matter on Soils

All soils are benefited by additions of organic matter. The nature of these benefits varies with soils; some are improved more than others.

Promoting Granulation. Organic matter as humus, or in colloidal form, and clay are essential for granulation or aggregation of soils. This condition is often called *crumb* structure. Mucks that contain colloidal organic matter granulate freely upon wetting and drying. Humus is nearly, if not absolutely, necessary for the granulation of clay soils. Wetting and drying and the accompanying swelling and shrinking of the organic matter are probably responsible for granulation in heavy soils. Freezing and thawing and soil organisms play their parts in the granulation of soils.

Holding Sand Grains Together. Well-decayed organic matter may be somewhat jellylike and sticky. When moist it holds the grains of sand together. Even when the soil dries out the humus still tends to hold the sand together.

Retaining Moisture. Organic matter that is only partly decayed takes up water and holds it like a sponge. Some plant materials hold water in an amount equal to several times their own weight. Coarsely granulated, heavy soils and sandy ones have large pores. If the granules resist breakdown in rains, heavy soils, like clays, permit water to percolate, or drain, through them readily. Heavy soils usually hold water satisfactorily, but sandy soils have such large pores that water readily drains out of them. Bits of organic matter in the pores swell upon wetting and partly close them. This change in the size of the pores enables the soil to hold more water than before the organic matter was mixed with the soil. This effect on the holding of water is more pronounced in fine- than in coarse-textured soils. In warm regions organic matter decays so rapidly that this effect on water-holding capacity does not last very long.

Reducing Soil Erosion. By loosening the soil, organic matter improves the movement of water into the soil. There is, therefore, less water to run off over the surface. Large granules are less easily moved by runoff water than are smaller granules or separate soil

particles. Coarse organic matter in the soil, on its surface, and as plant roots holds the soil against erosion.

Raising the Temperature of the Soil. Humus or other old, well-decomposed organic matter usually gives soils a dark color. Dark colors absorb and hold heat on bright days and thus raise the temperature of the soil. Moreover, because organic matter encourages percolation of water into the soil, the surface is drier and more easily warmed than is wet soil. Crops come up quicker and grow faster in early fall and spring on dark- than on light-colored soils that are much alike in other ways. This difference in temperature is brought about largely by the organic matter that gives soil its dark color.

Promoting the Work of Soil Organisms. Organic matter is the food of many of the organisms in the soil. Most of them depend entirely on organic matter for their energy. As a result of their effort to get food from organic matter, they produce acids. These acids attack the mineral part of the soil and make plant foods available to crops.

Supplying Nitrogen for Crops. Soil organic matter is the one natural source of nitrogen for crops. Most of the nitrogen in it is eventually made available to crops. Soils that are not manured or fertilized and do not receive regular additions of green manures or crop residues are rapidly depleted of active organic matter. In the northern part of the United States a loss of 1 ton of organic matter an acre per year is not unusual. Growing soil-exposing crops, and even good soil-management practices, generally encourage the decay of organic matter. This is as it should be, because the plant food released produces increased yields. Too rapid decay, however, leads to loss of plant food as well as organic matter from the soil.

5. Classifying Losses of Organic Matter from Soils

Organic matter may be lost from soils in many ways. Newly added organic matter is an active material. If it is not lost in other ways, soil organisms break it down to be lost from the soil.

By Erosion. It has been found that the soil material washed off sloping lands contains a higher percentage of organic matter than does the topsoil itself. In addition, pieces of dry organic matter on the surface are readily floated away in runoff water. Thus, erosion is an active agent in the loss of organic matter from soils.

By Fire. In some places farmers burn organic materials that have no immediate commercial value (Fig. 116). In certain localities straw is in this category; in others it has real value for bedding livestock and for mulching crops. Much less burning is done today than formerly, but too much of it is still done for the good of the soil. Burning such material as the stubble of small grains, the stalks of corn, broomcorn, and cotton, and such materials as the tops of potatoes is bad soil management because they are needed to replenish the organic content of soils. In burning, the nitrogen in crop

FIG. 116. Fire wasting organic matter. Not only are the organic matter on the surface and the nitrogen in it lost by such fires, but organic matter and nitrogen in the very topsoil also are lost. Prevent fires in so far as possible. If fires get started put them out if you can. (*T. L. Copley, U.S. Soil Conservation Service.*)

materials is liberated to the air and is a total loss to the soil. Unless crop residues are known to harbor harmful insects or plant diseases they should not be burned but should be returned to the soil.

By Decay and Leaching. Decay of these organic materials is natural and is necessary if plants are to grow on the soil. The reason is that plants need foods that can best be provided in this way. Soil organisms bring about decay of the crop residues and the liberation of these valuable by-products. If no plant roots are present to absorb them, they dissolve in soil water and are lost by leaching out in drainage water. There is a marked reduction in the loss of plant food, particularly nitrogen, from cropped as compared with bare soils. Consequently, cropping the land is an important way to decrease the loss of materials that come from organic matter.

By Cropping. Growing clean-cultivated crops encourages the process of decay as compared with growing grains and grasses or leguminous hay and pasture plants. Crops use the plant foods made available by decay organisms, and store them in the products. In such crops as wheat, vegetables, cotton, tobacco, or cabbage, much of the product is sold from the farm and is not returned to the land. On the contrary, crops that are fed on the farm are, at least in part, returned to the land in manure and the residues. The use of these materials by crops is to be encouraged in order to produce good yields. Make these losses good however, by returning organic matter to the soil.

By Fallowing. Cultivating the soil of dry-farming areas in alternate years in order to store part of one season's rainfall for use the following year is called *fallowing*. Weeds are not allowed to grow because they use up a large amount of water. During the year of fallow, conditions are exceptionally favorable for decay of soil organic matter. Much plant food is prepared during that year, and, when enough rain comes, some of it is lost. Rainfall, however, is usually not sufficient to cause severe leaching in dry-farming areas. Much of the summer rainfall comes as heavy showers that wash away available plant food and organic matter. Even though lack of plant food is less of a problem in the drier areas than it is in the more humid ones, the organic matter should be conserved and its supply maintained.

6. Returning Organic Matter to Soils

Soil organic matter decays whenever conditions are favorable for the growth of crops. There is no feasible way, therefore, to increase suddenly the supply of organic matter. In fact, to try to do so would be expensive. It is best to make frequent, moderate-sized additions of plant materials to the soil.

In Farm Manures. Farm manure is an excellent source of valuable organic matter. The digestive process that was started by the animal producing the manure is readily completed by the organisms of decay in the soil. The whole question of farm manures is treated in Chap. 9.

As Crop Residues. The more or less valueless materials left from crops are known as *crop residues*. They include the stubble and roots of small grains, hay crops, cowpeas, and soybeans, the stalks of corn, cotton, and sorghums, and the leftovers from vegetable crops. If

straw is not needed for bedding, it and similar materials are regarded as residues. These materials are of such value in the soil that burning them is usually poor soil management.

Corn stalks from a heavy crop may be so coarse as to be troublesome in the small grain and hay crops following. It is better, however, to cut them up rather than to burn them. Unless crop residues are known to be infested with destructive insects or infected by plant diseases, mix them with the soil. The stubble and weed growth after grains may be sufficient in wet years to be troublesome. Even so, such material is best put back into the soil.

The roots of crops are well distributed through the topsoil, and stubbles are rather uniformly scattered over the land. No work is needed, therefore, to spread them on the land. The stubble and roots of crops are often not fully appreciated. Their total weight from a thrifty growth of grain crops may be as much as 1½ tons (dry weight) to the acre. Stubble and roots of red clover and alfalfa may be 2 or 3 tons an acre or even more. These quantities of residues from leguminous hay crops explain the excellent growth of crops that follow clover, alfalfa, or other legumes. The long-term value of crop residues to both soils and crops is well established.

In Green-manure and Cover Crops. Like the roots and stubble of crops, green-manure and cover crops are naturally well distributed over the land. No labor is used to spread them, such as is needed for manure. This helps to hold down the cost of these crops and makes them attractive for the purpose of maintaining the organic content of the soil. Green manures are discussed in Chap. 10.

By Pasturing Crops. The management of pastures takes little labor. The droppings are pretty well distributed over the pasture lands, but scattering them once a year is desirable from the grazing standpoint. There is little loss of organic matter or plant food from droppings. From somewhat more than one-fourth to one-third of the dry matter in the pasturage is left on the grazed land. In some pastures, one-third of the nitrogen is returned to the land. This return per acre of manure from pasturage is often much higher than from the feeding of hay and grain. The loss from manure that takes takes place between its production and mixing it with the soil is relatively high.

By Rotating Crops. Rotating crops is far better than growing such soil-exhausting or soil-exposing crops as corn, potatoes, cotton,

and others, continuously. In contrast, growing alfalfa or other long-term hay containing a thrifty legume is better than a rotation that includes 1 or more years of clean-cultivated crops. Clean-tilled crops such as corn and cotton are heavy users of organic matter; small grains are intermediate; timothy and other grasses draw lightly on the organic content of soils. Leguminous hay crops, on the other hand, add nitrogen and organic matter to the soil. The beneficial effects of rotating crops vary with the crops that make up the rotation. Legumes and grasses are of greatest value to the soil and are helpful to the soil-exhausting crops in the rotation.

7. Adding Nitrogen to Soils

Nitrogen constitutes about three-fourths of the atmosphere by volume. This element is required in large quantities by crops. Until recently it has been expensive to purchase nitrogen for feed crops. Indications are that nitrogen will soon cost farmers less per pound than formerly. Because nitrogen is abundant, it is the job of the fertilizer manufacturer and the farmer to fix it so as to use it for the production of crops. Nitrogen is added to the soil in rainfall, by soil organisms, and in fertilizers, crop residues, and farm manures.

In Rain and Snow. Nitrogen is brought to the soil in rainfall, but the quantity to the acre varies somewhat. As an average for 11 years, 7.9 pounds a year of nitrogen an acre were brought to the earth in rain and snow together at Ithaca, New York. The quantity varied from year to year. It was much higher during the early part of the period than later. An average of between 5 and 7 pounds of nitrogen a year may be expected from rain and snow.

By Nonsymbiotic Soil Organisms. Several types of soil organisms gather nitrogen in one way or another and leave it in the soil. One group works independently in the soil; the members of this group are called *nonsymbiotic* organisms. These nonsymbiotic, or free-living, nitrogen-fixing organisms work best in soils that are around pH 6.0. Their work is slowed down if the acidity becomes much stronger than pH 6.0. In other words, they work best in soils of slight acidity. They would, of course, be expected to have a fairly high lime requirement. In fact, these organisms thrive in soils that are well suited to the growth of red clover.

The quantities of nitrogen fixed to the acre a year by them vary with other conditions. As an average for 11 years, 32 pounds of

nitrogen an acre a year were fixed in grass at the Cornell University Agricultural Experiment Station.[2] A slightly larger quantity was found as an average during a period of 20 years at Rothamsted, England. These organisms carry on their activities also in cultivated soils. In fact, they work wherever conditions are favorable for them. These additions of nitrogen to the soil took place without any leguminous plants being grown. The important point from the standpoint of the farmer is that fair-sized amounts of valuable nitrogen are added to the soil.

By Growing Legumes. That inoculated legumes gather nitrogen from the air has been known for a long time. At first, how they did it was a mystery, but it has been cleared up. Tiny plants called legume bacteria live in the tiny, whitish nodules on the roots of inoculated, leguminous plants. Here they collect nitrogen and hand it over to the host plant in exchange for food materials. It is for this reason that these are called *symbiotic* organisms. Long-lived legumes such as alfalfa and white clover fix more nitrogen than shorter-lived ones. The biennial, or two-year legumes, such as sweet clover and much of the red clover, also gather goodly quantities. The annual legumes such as soybeans, peas, (Fig. 117) and snap and dry beans fix smaller amounts of nitrogen yearly. More nitrogen is fixed if leguminous crops are alternated with grain crops than if legumes are grown alone year after year.

Red and alsike clover, mixed, appear to gather nitrogen more effectively than either variety of clover grown alone. If the soil is about equally favorable to both of these clovers, growing them together is best. Dry, deep soils are better adapted to red clover than to alsike. Soils that are moist most of the year, however, are better adapted to alsike than to red clover. Under these conditions, mixtures of red and alsike would not be expected to make as good growth or to fix as much nitrogen as the legume that is perfectly well adapted to a soil situation. Red and alsike clovers and mixtures of them may be expected to gather from 80 to 100 pounds of nitrogen an acre a year, or even more. Alfalfa may be counted on for a fixation of from 150 to 200 pounds of nitrogen an acre annually.

Inoculating Legumes. Getting the right nodule-forming bacteria onto the roots of legumes is called *inoculation.* The use of "artificial"

[2] Lyon, T. L., and B. D. Wilson, Some Relations of Green Manures to the Nitrogen of the Soil, *Cornell University Agricultural Experiment Station Memoir* 115, pp 27–28, 1928.

culture is the easiest method of inoculation. The bacteria are grown and put into moist, sandy soil, or the bacteria are "seeded" onto a culture material on which they grow. Here the organisms multiply until they are used.

Take up the organisms in a small quantity of water and pour it over the dry legume seed. Shovel it several times to distribute the bacteria over all the seed. Now dry the seed slowly—in shade, because bright sunlight and complete drying injures the organisms. Too much exposure kills them. After the seed is dry, sow in the

FIG. 117. Moderately inoculated pea seedlings. Inoculation was applied to the seed before it was planted. (*J. K. Wilson.*)

usual way. Because the organisms are short-lived in the dry condition, inoculated seed should be sowed not more than about 3 days after inoculation.

Legumes have been placed in groups that were inoculated by the same organisms. The formation of nodules by organisms from another group is called *cross inoculation.* Recently, however, these groups have been broadened greatly. If commercial inoculants are used, it is advisable to use the red-clover organism for red clover and the alfalfa organism for alfalfa and sweet clover.

Increasing Yields by Inoculating Legumes. Farmers have known for a long time that inoculating legumes increases yields (Figs. 118, 119,

120, and 121). Greater effects are obtained under some conditions than others. If acidity of the soil is too high, little benefit is obtained by inoculation. Wilson and Leland[3] obtained increased yields by inoculating the seed on both limed and unlimed soils. The increase in yield of red clover was more than one-third; of alfalfa, one-seventh;

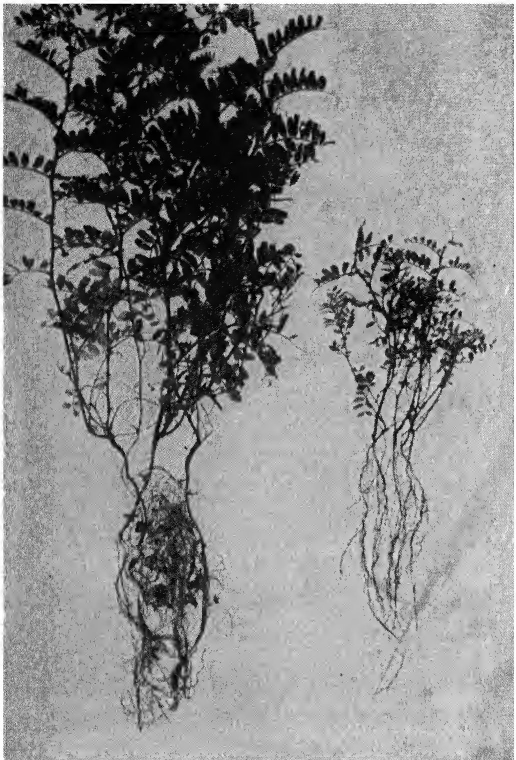


FIG. 118. Effect of inoculation on growth of vetch. Seed from which plants on left were grown was inoculated before planting; on right, not inoculated. (*A. L. Whiting.*)

of red kidney beans, about one-fourteenth; and of dry peas, one-fifth. Except for kidney beans, inoculation produced a greater increase on unlimed than on limed soil. Inoculating peas increases yields except on the heavier soils. Inoculation holds the peas in a tender condition and thus gives an increased percentage of the higher grades of product. The production of a larger percentage of higher-priced grades

[3] WILSON, J. K., and E. W. LELAND, The Value of Supplementary Bacteria for Legumes, *Journal of the American Society of Agronomy*, Vol. 21, pp. 474–586, 1929.

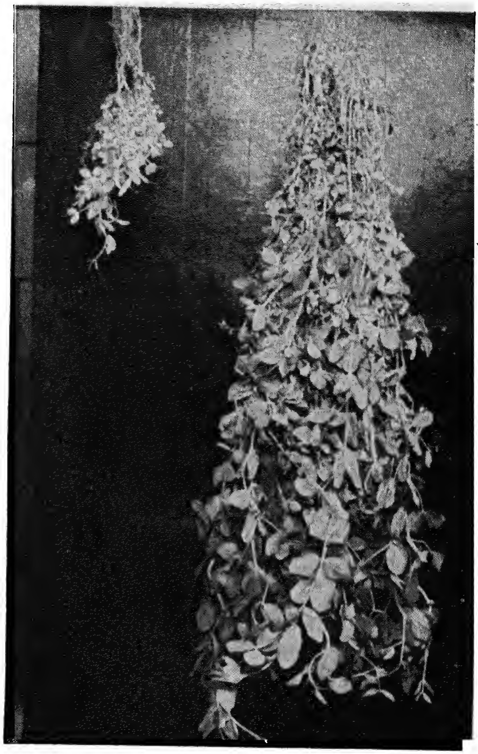


FIG. 119. Effect of inoculation on Austrian winter peas in Louisiana. Inoculation used on right; not on left. (*A. L. Whiting.*)

FIG. 120. Effect of inoculation of soybeans on farm of L. H. Smith, Illinois. The inoculated soybeans on the left not only produced a larger yield than the uninoculated ones but they competed more successfully with weeds. (*A. L. Whiting.*)

increases returns and justifies inoculation. Moreover, inoculation increases the nitrogen content, and presumably the feeding value, of leguminous hays. This increase may be as much as two-thirds of that in the hay from the uninoculated plants. Not only is feeding value improved by inoculation, but the roots and stubble decay quicker because of the higher nitrogen content. All in

Fig. 121. Effect of inoculating pea seed before drilling in Iowa. The larger growth and the darker color of the peas grown from the inoculated seed is apparent. The darker color results from the use in growth of the nitrogen gathered by the organisms working in the nodules on the roots of the crop. (*Urbana Laboratories, Urbana, Illinois.*)

all, inoculation produces really worth-while results, particularly if the low cost of inoculation is considered.

As Fertilizers. Nitrogen is applied to soils in increasing amounts by means of fertilizers. Food crops have received most of the nitrogen used in fertilizers. If the price becomes low enough, feed crops will get their share of nitrogen. This change could greatly increase the quantity of fertilizer nitrogen that is applied to soils.

In Crop Residues and Manures. Nitrogen is returned to soils in crop residues, in manures, in cover crops, and in green manures. The quantities of nitrogen that go back to the soil in these materials help greatly to maintain a suitable supply.

8. Making Nitrogen in Organic Matter Available to Plants

Organic matter and nitrogen undergo complex changes in the soil. The nitrogen was originally present largely as protein. Soil organisms decompose it to obtain their needs and ammonia is one of the by-products. Ammonia is changed to nitrite and this in turn to nitrate. These changes may be illustrated as follows:

$$\begin{array}{llll} \text{Complex nitrogen compounds} \rightarrow & \text{Ammonia} \rightarrow & \text{Nitrite} \rightarrow & \text{Nitrate} \\ \text{Protein} \rightarrow & NH_3 & \rightarrow NO_2 & \rightarrow NO_3 \end{array}$$

It should be understood that these nitrogenous materials readily combine with others in the soil. The ammonia may readily form ammonium hydroxide NH_4OH or ammonium carbonate $(NH_4)_2CO_3$, and the nitrite and nitrate readily combine with calcium to form calcium nitrite $Ca(NO_2)_2$ and calcium nitrate $Ca(NO_3)_2$. Although plants do use some nitrogen as ammonia, most of the nitrogen in nonleguminous crops is taken up in the nitrate form.

9. Hastening the Decay of Leguminous and Nonleguminous Residues

Leguminous residues such as clover and alfalfa stubble and roots decay quickly in the soil because of their high percentages of nitrogen. In so doing, the nitrogen and other plant food in them is soon made ready for use by the crop that follows. Nonleguminous materials such as the stubble and roots of grasses and grains decay slowly in the soil. The organisms are likely to take nitrogen from the soil and hold it temporarily to bring about decay of nonleguminous residues and very strawy manures. For this reason crops that follow a leguminous crop usually make larger and quicker growth than those that follow nonleguminous crops. Yields are usually correspondingly higher after such leguminous hay crops as clover and alfalfa (Fig. 122), than after such nonleguminous hay crops as timothy, orchard grass, millet, or Sudan grass.

10. Following the Nitrogen Cycle in Soils

The natural condition of soils may be regarded as the starting point in the nitrogen cycle (Fig. 123). Nitrogen is used by plants and stored temporarily in their products. At the same time nitrogen

is being lost in drainage and by washing away, and some goes directly back into the air.

Nitrogen is returned to the soil in manure after the crop is fed. Similarly, the nitrogen in the roots and stubble stays in and on the

FIG. 122. Effect of previous clover and timothy on growth of corn. Stubble and aftermath of well-inoculated clover was plowed down in comparison with timothy sod. The nitrogen fixed by the preceding clover produced the large corn on the left. Timothy preceded the corn on the right. (*Agronomy Department, Cornell University.*)

soil. The nitrogen that is fixed by legumes may help to make good these various losses. The nitrogen brought down as rain probably about makes up for the loss of nitrogen in drainage.

Thus, crops use nitrogen from the soil. Feed the crop and return the residues to the soil. Soil organisms decompose these materials

and make the nitrogen available to the crop that follows. From the soil back to the soil is a completed cycle. And so has one cycle followed another for many years.

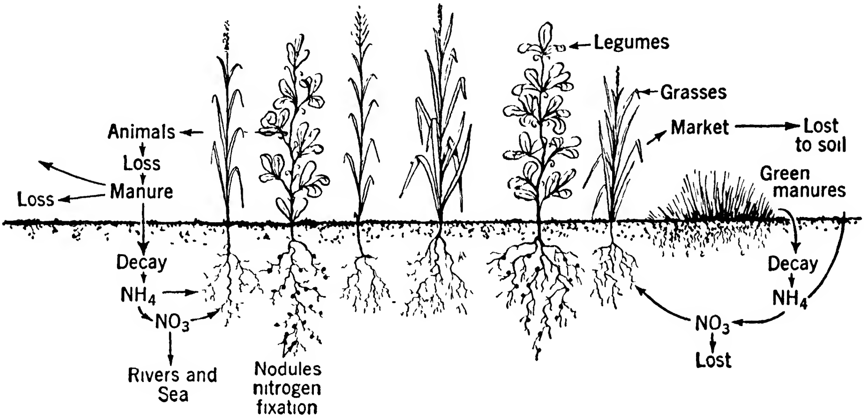


FIG. 123. Simplified nitrogen cycle. Part of some crops goes to market and the nitrogen is lost from the land. Some crops are fed and animals retain nitrogen. Nitrogen is lost also from manure in decay before it goes back to the soil. Some nitrogen is leached away to streams and eventually to the sea.

11. Maintaining Active Organic Matter and Nitrogen in Soils

Maintaining the supply of active organic matter goes hand in hand with keeping up the supply of nitrogen in the soil. Rainfall, non-symbiotic organisms, and legumes, together with crop residues, manures, and fertilizers serve to help maintain a supply of active organic matter and nitrogen in soils. Leguminous plants, however, are the foundation of extensive agriculture. Eighty pounds may be used as a very conservative estimate of the average annual fixation of nitrogen by legumes.

The commercial fertilizer nitrogen, at best, amounts only to a few pounds of nitrogen to the acre of cropland in this country.

Ten million acres of leguminous hay and pasture crops is a far smaller acreage than the farms of this country ought to produce each year. Yet 10 million acres at 80 pounds of nitrogen an acre a year amounts to 800 million pounds or 400,000 tons of nitrogen. This quantity exceeds even the rated capacity to produce fixed nitrogen in this country before World War II. What tonnage of nitrogen will be produced during the next few years it is too early to know.

We do know, however, that a greatly increased acreage of legumes should be grown on the nation's farms. It will be a long time before commercial nitrogen production can reach the total that should be fixed in the leguminous hayfields of the country. Using the product of commercial nitrogen-fixing plants should ease the problem of maintaining a suitable supply of nitrogen for crops and at the same time provide for the natural losses of nitrogen from soils.

SUMMARY

1. The natural organic matter in soils came mainly from the roots of the wild plants that occupied the land. The tops of plants made some contribution, as did animals, indirectly.

2. Organic matter varies widely in the proportions of carbon and nitrogen in it. The straws of grains are high in carbon and low in nitrogen. Leguminous materials, in contrast, are relatively much higher in nitrogen than straws. This condition explains the quicker decay of the stubble and roots of such crops as clover, alfalfa, and other leguminous plants than of grains.

3. Ammonia, and finally nitrates, carbon dioxide, and humus are among the highly useful products of the decomposition of organic matter.

4. Organic matter promotes granulation of heavy soils, tends to hold sand grains together, retains moisture and reduces erosion, tends to raise the temperature of soils, promotes the work of soil organisms, and, upon decay, supplies nitrogen for crops.

5. Organic matter may be lost from soils by erosion, by fire, by decay and leaching, by cropping, and by fallowing.

6. Organic matter may be returned to the soil in farm manures, crop residues, in green-manure and cover crops, by pasturing, and by rotating crops.

7. Nitrogen may be added to soils by catching precipitation, through the work of free-living organisms in the soil, by growing inoculated legumes and returning to the soil the manure that results from feeding them, by using fertilizers containing nitrogen, and by adding crop residues and green and farm manures to the soil. To be most effective in adding nitrogen, manures should be protected from leaching by rains.

8. In order that the nitrogen in organic matter may become available to crop plants it must decay. Keeping the soil in good condition to produce crops aids soil organisms in the work of breaking down organic matter. The organisms take from organic matter what they need for growth; ammonia and nitrates are by-products of the work of these organisms.

9. Nitrogen goes through a more or less definite cycle. Through the

help of legume organisms these plants obtain nitrogen from the soil air. The plants are harvested and fed to farm animals and the manure is returned to the soil. Here the manure decays, and the nitrogen and other plant foods in it are released to be used again by plants. Some of the nitrogen may be sold in crops. Some nitrogen goes back to the soil directly in roots and stubble and some in green-manure and cover crops. Some nitrogen, of course, goes back to the air and some is lost out of the soil in the drainage water.

10. Maintain organic matter as nearly as possible. It is absolutely essential in productive soils, but organic matter alone seldom keeps crop yields at a high level.

9. Conserving and Using Farm Manures

CONSERVING and using farm manures requires more consideration than the subject often receives. Farmers and students of crop production and soil management need to give it serious attention. The large quantity of manure produced by the livestock on the average-sized farm has real value. If conserved and rightly used, this manure can do much to help to maintain crop yields and the long-term productivity of the soil.

Most of the grain and forage crops grown on general and livestock farms is fed right on the farm. The manure that results is a valuable by-product of this type of farming. Formerly, a good many farmers treated manure as something to be disposed of as easily as possible. The wise farmer cares for manure and uses it for the production of even larger yields. Conserving and using farm manures will be discussed under the following headings:

1. Producing Farm Manures
2. Comparing the Composition of Farm Manures
3. Comparing the Properties of Farm Manures
4. Conserving Farm Manures
5. Using Farm Manures
6. Making Artificial Manure from Straw, Leaves, and Leftovers
7. Determining the Dollar Value of Manures

1. Producing Farm Manures

The quantity of manure produced depends on the quantity of feed grown and purchased, the kind and quantity of bedding used, and the age, kind, and number of animals kept on the farm.

The kind, digestibility, and quantity of feed used influences the quantity of manure produced. The grain part of corn is largely digested; only about one-tenth of its dry matter is in the manure. In contrast, more than one-half of poor-quality timothy hay is recov-

ered as manure. Of grasses and green legumes about one-third, and of good clover and alfalfa hay two-fifths is found in the manure.

Bedding Animals. Bedding materials vary considerably as do also the quantities used. In areas that produce little straw, bedding is used sparingly in comparison with the free use of straw in regions that produce much grain. A dairy cow needs nearly 2 tons of bedding a year or about 1 ton for a 6- or 7-month barn-feeding period; more or less is needed for longer or shorter stabling periods. Chopping straw improves its absorption of water, but long straw stays in place better than short straw. Shavings from planing mills and sawdust are sometimes used for bedding. There is objection to shavings from high-resin woods, but none to those from broad-leaved hardwoods such as oak, hickory, ash, walnut, and others.

In sections where bedding materials are scarce and expensive, less than 2 tons for an animal is used. With less bedding the manure is more concentrated than when a generous amount is used. Moreover, such manure is wet and not very easy to handle. Wheat and rye straw retain more than twice their weight of water and oat straw nearly three times its weight. Sawdust and shavings hold nearly four times their weight of water. Sawdust, however, is somewhat more absorbent than shavings.

Feeding Animals. Production of manure varies with animals; some retain more of certain elements in the feed than do others. Young, growing animals and dairy cows retain more of the phosphorus and nitrogen found in feeds than do mature, fattening animals and work horses and mules. Among mature animals (per 1,000 pounds of live weight) there is no great difference in the quantity of manure produced on the basis of dry weight; the horse is highest and the dairy cow lowest. In total weight of wet manure, including the liquid, cows and pigs are highest and hens and sheep lowest.

There is wide variation in the feeds used by these animals. Pigs and hens consume a more concentrated ration and relatively a greater quantity of it than do the other classes of animals.

The production and composition of manures is given in Table 15.

Animals produce large quantities of manure per 1,000 pounds of live weight. On the basis of the figures in Table 15, dairy cows produce 13 tons of manure, horses 9¼, pigs 15, sheep 6½, and hens 5 tons of manure including all the liquid. Not all of the manure is recovered to haul out because some is voided on pastures or in the

fields. Cows produce about 9 tons including 1 ton of bedding, for a barn-feeding period of 7 months and, of course, correspondingly less manure for shorter periods.

TABLE 15. AMOUNT OF AND PLANT FOOD IN THE MANURE PRODUCED BY ANIMALS*
Per 1,000 pounds live weight

Animal	Constituent	Annual production, pounds	Water, per cent	Dry matter, pounds	Nitrogen, pounds	Phosphoric acid, pounds	Potash, pounds
Horse	Liquid	4,000	90	400	60	Trace	48
	Solid	14,500	70	4,350	66	44	58
	Total	18,500	74	4,750	126	50	106
Cow	Liquid	8,000	93	560	64	Trace	80
	Solid	18,000	80	3,600	63	36	45
	Total	26,000	84	4,160	127	40	125
Pig	Liquid	12,000	96	480	60	12	72
	Solid	18,000	78	3,960	54	45	54
	Total	30,000	85	4,440	114	57	126
Sheep	Liquid	4,500	87	585	68	23	57
	Solid	8,500	55	3,825	68	34	43
	Total	13,000	66	4,410	136	57	100
Hen	Total	10,000	55	4,500	130	80	90

* FIPPIN, E. O., Farm Manure, Lesson 141, *Farm Reading Course, New York State College of Agriculture*, p 175, 1919.

The manure produced by the Cornell University Agricultural Experiment Station herd was determined for a week. The data are given in Table 16. The annual production of manure for 1,000

TABLE 16. QUANTITY AND NITROGEN CONTENT OF FEED CONSUMED AND QUANTITY AND NITROGEN CONTENT OF MANURE PRODUCED BY A DAIRY HERD
Per 1,000 pounds live weight

	Daily amount	Annual amount
Clear excrement produced	75.5 pounds	13.75 tons
Excrement produced with bedding	85.7 pounds	15.60 tons
Organic matter consumed	21.1 pounds	7,700 pounds
Organic matter voided	9.18 pounds	3,350 pounds
Proportion of organic matter regained	43.3 per cent	....
Nitrogen consumed	0.585 pounds	215 pounds
Nitrogen voided	0.26 pounds	94 pounds
Proportion of nitrogen regained	44.3 per cent	....
Proportion of ash regained	63.6 per cent	....
Proportion of water in manure	81.8 per cent	....

pounds live weight was calculated and is shown in the second column. These figures are slightly higher than those for a cow as shown in Table 15.

2. Comparing the Composition of Farm Manures

Composition as well as quantity of manure produced is shown in Table 15. Figures for the average plant-food content of manures are useful in many discussions. The average composition of mixed manures is given in Table 17. On the average, manure contains 25 pounds of plant food per ton and is dilute when compared with fertilizers.

TABLE 17. AVERAGE COMPOSITION OF MIXED MANURES

	Dry matter	Nitrogen	Phosphoric acid	Potash
Per cent	20–25	0 5	0 25	0.5
Pounds per ton	400–500	10 0	5 00	10 0

Estimating Liquid-manure Values. On the basis of the data shown in Table 15, about one-half of the nitrogen and three-fifths of the potash is in the liquid part of farm manures. The liquid part of pig and sheep manures contains appreciable quantities of phosphorus, but horse and cow manures have only traces of phosphorus. The nitrogen and potash in the liquid are readily available to crops and for this reason are of greater value than are these plant foods in solid form. The nitrogen breaks down easily, however, and may readily be lost. Because these plant foods are in the liquid they are easily washed out by rains. Protection from rain and snow is desirable, therefore, to prevent undue loss of these materials.

In Europe, liquid manure is often conducted into a cistern and from there pumped into tank wagons, hauled out, and applied to the land. A few farms in this country employ similar methods for making effective use of liquid manure.

Provide tight stable floors to hold the liquid and plenty of bedding to absorb it. The straw with the liquid is mixed with the solid and they go to the field together. Try to save all of the liquid manure possible, because the soils of most farms are in real need of *all* the nitrogen and potash in liquid manure. Moreover, most of the plant

foods come from the soil and must go back into it; otherwise the productivity cannot be maintained except at high cost for purchased fertilizer.

Estimating Dried-manure Values. Dried manures have come into increasing use during recent years. To dried sheep manure, which has been used for years, have been added dried cow, goat, and poultry manures. Some manures are dried at ordinary air temperatures and others are dried with artificial heat. By the latter method the drying can be done more quickly and completely than by simply air-drying. The comparison of plant-food content in dried manures is given in Table 18.

TABLE 18 COMPOSITION OF DRIED MANURES*

Animal	Nitrogen, per cent	Phosphoric acid, per cent	Potash, per cent
Sheep	2 50	1 50	1 50
Goat	1 35	1 40	3 60
Poultry	4 50	3 20	1 35
Pig	1 75	1 75	1 00
Cow	1 34	0 90	0 85

* VAN SLYKE, L. L., "Fertilizers and Crop Production," p 171, Orange Judd Publishing Co, Inc, New York, 1932

The plant-food content of dried manures is much higher than that of natural manures because of the low water content of the dried ones. Although somewhat expensive because of all the work that has been done on them, dried manures can be used advantageously for window boxes, potted plants, greenhouse production, and small gardens and lawns. Dried manures are sufficiently concentrated to burn plants if they are applied too liberally.

3. Comparing the Properties of Farm Manures

Pig manure contains 78 per cent and cow manure 80 per cent of water in the solid excrement. Because they are wet, these manures decay slowly and remain cool. For these reasons they are often called "cold" or "wet" manures. In comparison, hen manure contains 55 per cent of water, the solid excrement of horse manure 70 per cent, and that of sheep manure 55 per cent. Because of their consistency and their relatively low water content, these manures decay readily

at any temperature, hot or cold, and are called "hot" or "dry" manures. Steaming "craters" in snow-covered piles of horse manure are frequently seen in the northern states.

Freshly produced manure contains billions of decay organisms in every pound. They begin their work in the digestive tract and complete it after the manure is voided by the animal. There is no break in the process; their work goes on to completion. In detail, the composition of manure changes somewhat rapidly for a time and later more slowly; however, change is taking place except when it is frozen.

In spite of the fact that average figures are used for the plant-food content of manures, they are really *variable* in composition. It must be remembered that manures vary with the animal, its feed, age, and work, and with the kind and quantity of bedding used. In addition, water from both rain and snow dissolves and leaches out much soluble plant food from manure that is exposed to the weather.

In comparison with fertilizers, ordinary wet manure is *bulky* as well as dilute. Some of the more concentrated fertilizers carry 30 to 40 times as much plant food to the ton as does a ton of ordinary manure.

Manures do not rot in the soil and give up all their plant food to crops in one season. There is some carry-over or *residual* effect on the crops that follow. The residual effect is more on some soils than on others. In loose, open, light, sandy, or gravelly soils, decay is nearly complete during the season in which manure is applied. In heavy silt loams and clayey soils, where decay is less rapid because of insufficient aeration, the carry-over effect is more pronounced. On well-drained, fairly heavy silt loams, crops get about one-half of the value of manure the first year, about one-fourth the second year, and the rest over the following year or two. Heavy applications have more residual effect than do light ones. The latter, in fact, do not show any marked residual benefits.

4. Conserving Farm Manures

As previously stated, manure contains millions of decay organisms at the time it is produced. These organisms continue the breakdown of the manure, and carbon dioxide is one of the products. Carbon dioxide may be lost from the manure either as gas or by drainage after it is dissolved in the moisture of the manure. Some of the carbon dioxide may combine with ammonia to form soluble ammonium

carbonate, and thus be carried away in rain water. The sharp odor of ammonia is often noted in barns and stables, particularly horse stables. This is gaseous ammonia. In warm weather, piles of "hot" manures lose large quantities of ammonia, and a heavy loss of nitrogen thus takes place.

Recognizing What May Be Lost. Rainfall on wet manure leaches out the liquid part of it. Moreover, as stated in the preceding paragraph, carbon dioxide and ammonia are lost to the air and by being drained out of the manure. Determinations of these losses were made at the Cornell University Agricultural Experimental Station some years ago. One lot of cow manure and one of horse manure were piled out in the open on April 25 and weighed on September 22, a period of 5 months. The quantities of manure used and the losses of organic matter and plant foods are shown in Table 19.

TABLE 19. LOSSES OF ORGANIC MATTER AND PLANT FOOD FROM MANURES IN STORAGE DURING SUMMER *

	Weight of manure Apr. 25, pounds		Weight of manure Sept. 22, pounds		Percentage of loss	
	Horse	Cow †	Horse	Cow	Horse	Cow
Total weight	4,000	10,000	1,730	5,125	57	49
Nitrogen	19 6	47	7.79	28	60	41
Phosphoric acid	14.8	32	7 79	26	47	19
Potash	36 0	48	8 65	44	76	8

* ROBERTS, I P, The Production and Care of Farm Manures, *Cornell University Agricultural Experiment Station Bulletin* 27, pp. 32-33, 1891.

† Three hundred pounds of gypsum added at beginning.

The loss in weight of dry matter was largely a loss of organic matter. More than one-half of the dry matter in the horse manure and nearly one-half of that in the cow manure was lost by rotting and then leaching away in drainage water. Three-fifths of the nitrogen was lost from the horse manure and two-fifths of that in the cow manure during those 5 summer months in the cool weather of Ithaca, New York. Nearly one-half of the phosphoric acid was lost from the horse manure and one-fifth from the cow manure. The respective losses of potash were three-fourths from the horse manure and one-twelfth from the cow manure. It should be noted, however, that 300 pounds of gypsum was mixed with the cow

manure at the beginning of the test. Its effect, if any, on losses is not apparent from this experiment.

Manure that was out in the open in New Jersey for 2 months lost one-half of its nitrogen and potash and slightly less than one-half of its phosphorus. Manure from steers that was exposed for 3 months in Ohio lost two-fifths of its organic matter; horse manure lost nearly three-fifths in the same time. Of course, conditions were not exactly the same, but the horse manure in Ohio lost 57 per cent of its organic

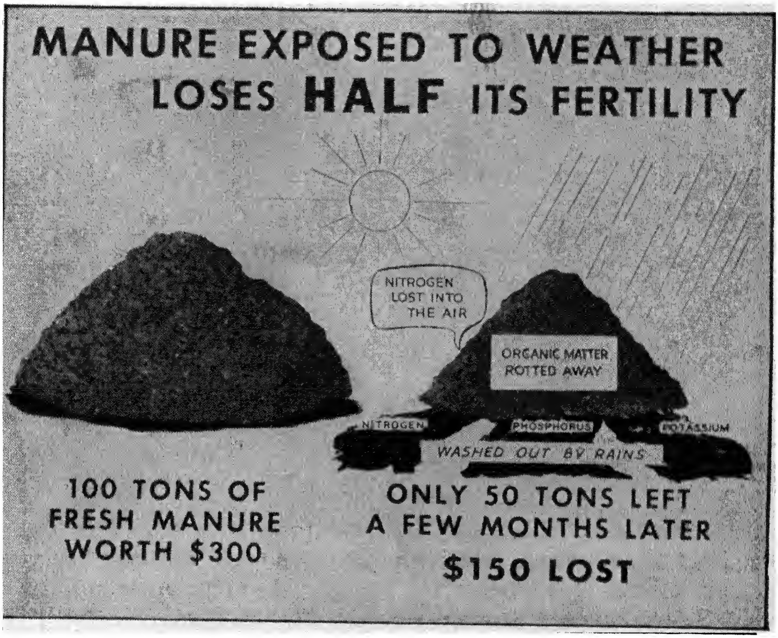


FIG. 124. Heavy loss from manure in warm weather. (*C. M. Linsley and F. H. Crane, University of Illinois.*)

matter in 3 months and that at Ithaca 57 per cent in 5 months. Losses may be expected to be larger in higher temperatures, and average temperatures should be a little higher in Ohio than in New York.

On the basis of experimental work and practical observations, manure in a loose, exposed pile may be expected to lose from one-half to two-thirds of its organic matter, nitrogen, and potash, and two-fifths of its phosphorus in one summer (Figs. 124 and 125). Because most soils have lost so much of their natural organic matter and plant-food supply, losses from manure must be avoided. Every pound of available manure should go back into the soil.

Manures contain considerable quantities of organic matter. According to Table 15, 1 ton of cow and pig manures (solid and liquid) contains 300 pounds of dry organic matter; horse manure, 520; sheep, 780; and hen manure, 900. This organic matter is particularly valuable in soils because it decays readily and builds up the humus content of the soil. It also helps to provide soils and crops with all the benefits of organic matter that are discussed in Chap. 8.

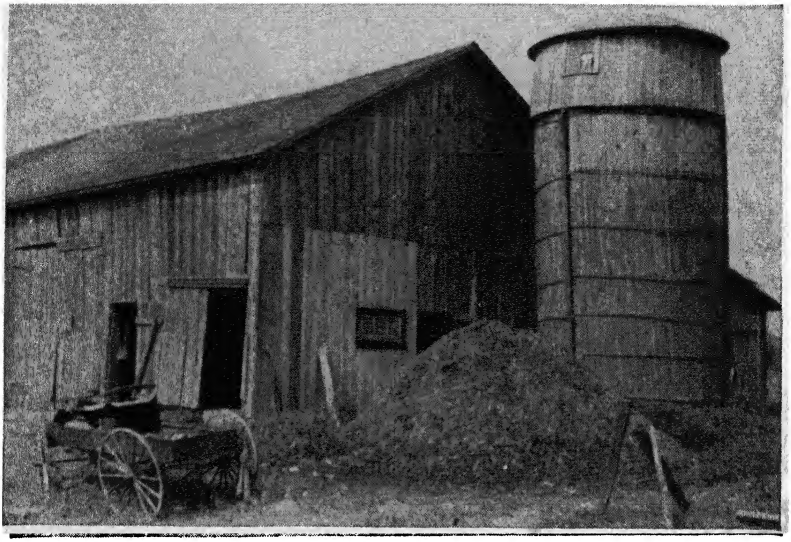


FIG. 125. Manure losing valuable nitrogen and organic matter. Manure that lies in a pile like this over summer loses about one-half of its value in the northern states. In warmer climates losses are correspondingly greater.

Reducing Losses From Manures. There is no way to prevent losses of organic matter and plant foods from manures, but losses can be reduced. Some methods can be employed on nearly all farms and others on most farms. Among the practicable ways are (1) spreading the manure daily or before much loss has taken place; (2) protecting it from rain and snow; (3) packing it; and (4) keeping it moist. In addition, some preservatives have practical value.

Spreading Manure While Fresh. On many dairy farms in the Northeast it is common practice to haul the manure to the field and spread it every day (Figs. 126, 127, and 128). Of course, the snow becomes too deep and fields too soft for spreading at times. Then it must be piled for later spreading. Some loss of soluble plant food, such as

FIG. 126. Taking manure direct from stalls to spreader in a litter carrier. The manure is pitched by hand into the carrier but no other hand work is done on it. (*C. M. Linsley and F. H. Crane, University of Illinois.*)

FIG. 127. Handling manure with a mechanical loader. Manure from a paved lot, pile, box stall, or basement barn may be put onto a spreader or wagon with the manure loader. Manure thus loaded may be spread on the land without any hand labor. Such loaders are now available through implement dealers or they may be homemade. (*C. M. Linsley and F. H. Crane, University of Illinois.*)

that in the urine, takes place when snow thaws or heavy rains fall on frozen soil. Is this loss after manure has been spread greater or less than from a pile in the barn lot? This live question is often debated when farmers get together. Information of value on this question is found in a comparison that was made a few years ago at the Ohio Agricultural Experiment Station. Manure that was hauled out and

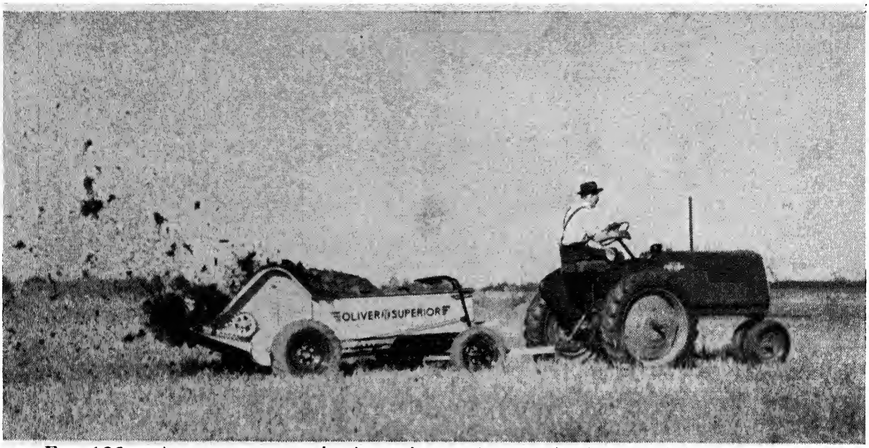


FIG. 128. A manure spreader in action. A spreader is essential to obtain the full value from manure. Uniform, thin spreading gives good results. Haul the manure to the fields daily. (*The Oliver Corporation.*)

spread on the land early in January was called "stall" manure. The same quantity of manure, piled in the barnyard in January, was gathered up and spread on the land about the first of April. This was termed "yard" manure. The comparative effects on crop yields are shown in Table 20.

TABLE 20. INCREASES IN YIELD FROM PROTECTED AND EXPOSED MANURES*

Condition of manure	Corn (21 crops)	Wheat (21 crops)	Hay (18 crops)
	bushels	bushels	pounds
Protected† (stall)	32.6	14.8	2,214
Exposed (yard)	28.4	13.3	1,667
Gain for spreading in January	4.2	1.5	547

* THORNE, C. E., and Staff, The Maintenance of Soil Fertility, *Ohio Agricultural Experiment Station Bulletin* 336, p. 615, 1919.

† Both "protected" and "exposed" manures used with same quantity of superphosphate.

These differences in yields constitute a good answer to the question about relative losses from these ways of handling manure. The manure put on the land in January produced 4.2 bushels more corn and 1.5 bushels more wheat, as a 21-year average of 2 plots each year, and 547 pounds more hay (18-year average) than the manure that was spread April 1 after it had lain in the open for 3 months.

In general, 1 ton of fresh manure spread on the land may be expected to increase yields by from 50 to 100 per cent more than it would if it had lain in the usual pile throughout the summer months. Spreading manure for feed crops as soon as possible after it is made pays well and is good for the soil.

Protecting Manure from the Weather. If manure cannot be spread soon after being made, protect it in some practical way. The roof over it need not be expensive. The important thing is to keep rain and snow off the manure. In Canada, Shutt determined the benefits of protecting manure. One pile of mixed cow and horse manure was exposed to rain and snow and the other was kept under cover. The benefits of protection are shown in Table 21.

TABLE 21. EFFECTS OF PROTECTION AND TRAMPING ON LOSSES FROM MANURE IN STORAGE

Conditions and location	Losses, per cent			
	Organic matter	Nitrogen	Phosphoric acid	Potash
Canada:*				
Manure stored 1 year				
Protected....	60	23	4	3
Unprotected.....................	69	40	16	36
Pennsylvania:†				
Manure stored 6 months (tramped by young stock)............ . .		5.7	8.5	5 5
Protected (not tramped at all)		34 1	14 2	19 8

* SHUTT, FRANK T, Barnyard Manure, *Canadian Department of Agriculture Central Experimental Farm Bulletin* 31, p 19, 1898.

† FREAR, WILLIAM, Losses in Manure, *Pennsylvania Agricultural Experiment Station Bulletin* 63, p 5, 1903.

The saving of organic matter by protecting the manure was not large. The savings of nitrogen and particularly of phosphoric acid and potash were large. These savings amount to 1.7 pounds of nitrogen, 0.6 pound of phosphoric acid, and 3.3 pounds of potash to

the ton of protected manure. On the basis of 200 tons of manure to the farm this is a saving of 340 pounds of nitrogen, 120 pounds of phosphoric acid, and 660 pounds of potash a year. This quantity of nitrogen is equivalent to that in 6,800 pounds of 5–10–5 fertilizer, the phosphoric acid to that in 1,200 pounds, and the potash to that in 13,200 pounds. (See Chap. 11.) Expressed in this way the advantage of protecting manure is perfectly evident.

Workers in Pennsylvania conducted a comparison to learn the effect of tramping manure and of leaving it in a loose pile. Both piles were under a roof and protected from rain and snow. The differences are shown in the second half of Table 21. Young stock ran over the manure and compacted it. This kept out much of the air which is necessary for rapid decay. Tramping reduced all losses of plant food to very small proportions; it is a very effective way of saving manure. Keeping manure moist in storage also is a great help in protecting it against heavy loss.

On many farms feeder lambs or steers, young stock, breeding stock, dry cows, and on some farms milk cows also, run in sheds or basement barns. They are bedded to keep them dry and comfortable. The manure is compacted and kept moist as it accumulates. Handling manure in this way prevents leaching, excludes air by tramping, and keeps it moist. Losses of ammonia and organic matter are relatively small from such manure. For many farms this method of managing manure is next in economy and efficiency to hauling it to the field and spreading it daily. This kind of manure, moreover, is excellent for top-dressing meadows, new meadow seedings, and wheat. In some sheds and barns the mechanical manure loader can be used to save much hard hand work.

Storing Manure in Deep Piles. On some farms there is no better way than to store manure in a deep pile (Fig. 129). Make the pile at least 5 or 6 feet deep. Have the sides as near perpendicular as convenient, to avoid shedding rain. Such a pile has a flat or slightly dished top to take in the rain. Sufficient depth enables the wet manure to compact itself by the action of gravity. The compacting keeps out much air and checks the action of the decay organisms. The moisture takes up the gaseous ammonia and holds some of it against loss. The depth of the pile is sufficient so that there should be little liquid lost from it. To the degree that these conditions are satisfied, losses are low from manure in deep piles.

Storing Manure in Pits. If manure is to be stored as a year-in and year-out practice, a manure pit deserves consideration. Provide a watertight pit to hold the liquid manure and to hold soluble plant food against being leached out and lost. Dry manures (horse, sheep, or hen) may be improved by allowing the rain to fall on them, thus keeping them too moist to rot and heat excessively. Plan pits that are relatively inexpensive because they cannot prevent loss entirely; they can only hold it to a reasonable minimum. Losses, however, are lower in pits than in exposed, loose piles.

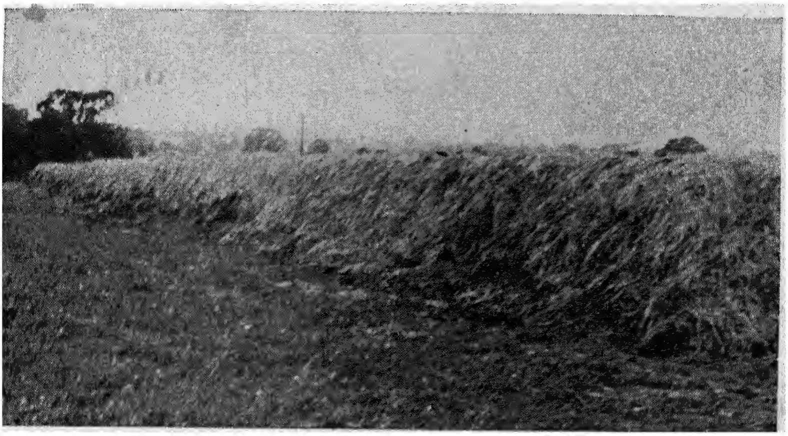


FIG. 129. Storing manure in deep piles. A flat-topped, steep-sided pile holds most of the rain that falls on it. This absorption helps to keep the manure moist, and the pile is deep enough to compact itself. Compact, moist manure does not rot as rapidly as shallow, loose manure.

5. Using Farm Manures

Manure usually requires no cash outlay because it is a by-product of animal farming. Although it is dilute, there is so much of it that the total supply carries a large quantity of plant food. Few farms produce so much manure that heavy applications can be made on some fields without robbing other acres of what should go back to them.

Supplementing Manure with Phosphorus. Average mixed manure, it has been stated, carries 10 pounds of nitrogen, 5 of phosphoric acid, and 10 pounds of potash to the ton (Fig. 130). A high-analysis mixed fertilizer, in comparison, has 100 pounds of nitrogen, 400 pounds of phosphoric acid, and 100 pounds of potash to the ton.

From these figures, the relative diluteness of manure is apparent. Manure carries 25 pounds of plant foods and this fertilizer has 600 pounds to the ton. Another way to compare is that 200 pounds of 5–20–5 has the same quantities of nitrogen and potash as 1 ton of manure. This quantity of the fertilizer contains 40 pounds of phosphoric acid or 8 times that in 1 ton of manure. This comparison gives

FIG. 130. Supplementing manure with phosphorus in the stable. The amount of superphosphate to use will vary somewhat with quantity of manure and superphosphate it is planned to use to the acre. Use superphosphate this way in the stable. (*American Agricultural Chemical Co.*)

an idea of the relative shortage of phosphoric acid in ordinary farm manure.

For grains and, in fact, for most crops, manure is short on phosphoric acid. The only way to remedy this condition is to add phosphorus. The effect on yields of supplementing manure with phosphorus is shown in Table 22.

Adding phosphorus to stall manure increases materially yields of corn, wheat, and hay. The superphosphate used is equivalent to

224 pounds of the 20 per cent analysis for 3 years or about one-half of what is now generally recommended for these crops in the Northeast. A larger application would undoubtedly have further increased the yield. Rock phosphate increased the yield in tests made, even though the application was extremely light.

TABLE 22. CROP INCREASES FROM PHOSPHORUS IN ADDITION TO FARM MANURE*
(Average for 26 years, 1897–1923)

Wooster silt loam, 8 tons manure per acre	Crop yield increase per acre		
	Corn, bushels	Wheat, bushels	Clover, pounds
Stall manure only	23 9	10 0	1,281
Stall manure + 320 lb. of 14 per cent superphosphate	34 3	15 1	2,196
Stall manure + 320 lb. of rock phosphate †	30 1	12 9	1,775
Gain for superphosphate over manure . . .	10 4	5 1	915
Gain for rock phosphate over manure	6 2	2 9	494

* THORNE, C E , and Staff, The Maintenance of Soil Fertility, *Ohio Agricultural Experiment Station Bulletin* 381, p. 326, 1924

† Rock phosphate usually carries about 30 per cent of phosphoric acid

Phosphorus can be used in several ways to supplement manure. A popular way on dairy farms is to scatter about 2 pounds of 20 per cent superphosphate per cow, or its equivalent in other analyses, on the manure or in the gutter and driveway after the stable is cleaned (Fig. 130). Next morning sweep the superphosphate into the gutter and take it out with the manure. Two pounds a day for a 7-month feeding period makes 420 pounds with about 9 tons of manure. If manure is put on at a rate of 10 tons to the acre, 467 pounds of this superphosphate goes onto each acre for the period of the rotation. A 3-year rotation of feed crops should do well with this treatment. Increasing the superphosphate to 2½ or 3 pounds a cow daily will be satisfactory for 4- or 5-year rotations of feed crops. These quantities of superphosphate are used for a 10-ton application of manure. If the rate of manuring is changed, change that of superphosphate also. If the rate of manuring is 8 tons, the use of superphosphate must be increased to 2½ pounds a cow daily. If, on the other hand, the rate of manuring is increased to 12 tons an acre, five-sixths as much, or 1⅔ pounds of superphosphate a day per cow is needed to put on 467 pounds of 20 per cent superphosphate in 12 tons of manure an

acre. Similar changes would be needed for higher rates of application of superphosphate. In exactly the same way, rock phosphate can be used where it is desired. For a few rotations the rate of application may well be from two to four times that of superphosphate. After that, decrease the quantity or use rock phosphate once in 6 or 8 years, instead of for each rotation. Leguminous crops make the best use of rock phosphate.

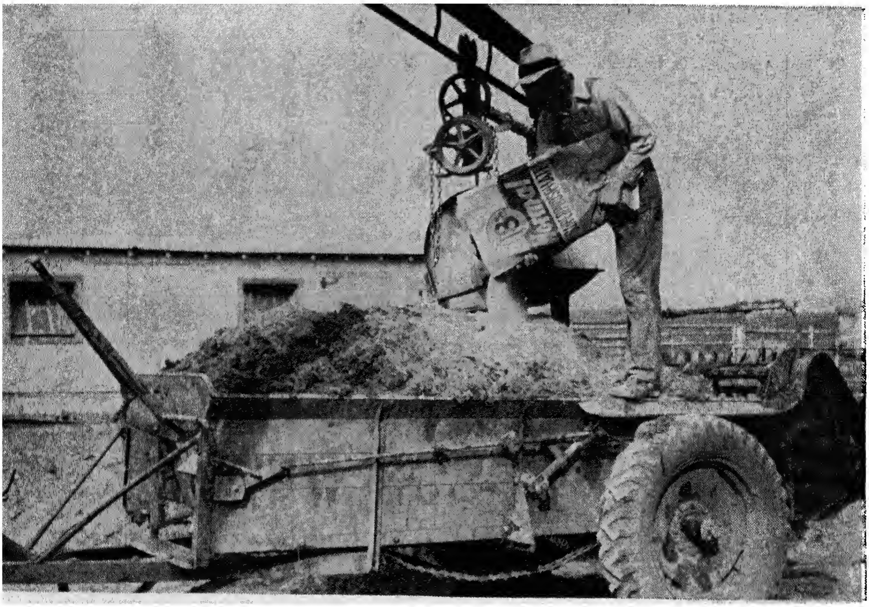


FIG. 131. Supplementing manure on the spreader with phosphorus. If it is not convenient to use superphosphate in the stable, it can be put on each load of manure before it goes to the field. (*American Agricultural Chemical Co.*)

Manure can be supplemented with phosphorus by putting it on the spreader load as it goes to the field (Fig. 131). If a 10-ton application is being made and 450 pounds of superphosphate are being used to the acre, scatter 45 pounds of superphosphate over each load to put on 450 pounds to the acre. This quantity, of course, is for the benefit of an entire rotation of 3 or 4 years. Rock phosphate would probably not be sufficiently well mixed with the manure in this way. Either rock phosphate or superphosphate may be applied separately on land that is being manured. Intimate mixing with the manure is more important with rock phosphate than with superphosphate.

Manuring Crops. Crops generally respond to manuring, but there are differences in response. Because manure is relatively high in nitrogen and potash, applications of it are especially beneficial to hay and pasture crops and leafy vegetables. Even most of these need more phosphorus than manure supplies. Grains and crops that mature seed make good use of manure, but in relatively light applications.

Use light applications of manure on wheat in late fall or early winter. So used, manure reduces the amount of freezing and thawing, holds snow, and tends to lessen the damage done by heaving. This manure protects the grain from the extreme drying effects of cold winds. Use a light coat of manure to help check movement of soil by both wind and water when the soil is bare in winter or early spring.

Manure is used on new meadow seedings after the grain has been harvested. The young clover and grass plants are greatly benefited immediately and later, much the same as wheat. On unlimed, acid soils, manure often makes the difference between a poor stand and a good one. Mature meadows make good use of manure. Manuring a meadow in the spring of the final year it is cut for hay is good practice. The hay crop is greatly benefited, and the improved sod and the residual effect of the manure improve the following corn or other crop.

Ways of Putting on Manure. Manure, on the smaller farms particularly, is spread by hand. Uniform distribution by hand takes time and is not easy work. The result is that too often manure is *unloaded* rather than *spread* by hand (Fig. 132). The manure spreader saves time and does a better job than hand spreading. The spreader shreds, or tears up, the manure as it spreads it. The manure falls in close contact with the soil and may not dry out completely. Spreading of manure is done easily, evenly, and most satisfactorily, therefore, with the manure spreader. Probably no implement on farms where the average quantity of manure is produced pays for itself so quickly as does the manure spreader (Fig. 128).

Time of Spreading Manure. The best time to spread manure is daily as it is produced. For cabbage, corn, and other intertilled crops, put manure on at any time after the preceding crop has been harvested, but before plowing. For most cultivated crops it is desirable to mix manure with the soil. Coarse manure on the surface

interferes with seedbed preparation, seeding or planting, and with cultivation of the crop. Well-rotted manure can be put on the surface without any of these objectionable results.

Manure may be put on the surface of sandy soils after the crop is planted. Here, as elsewhere with surface application, fine or well-rotted manure gives less trouble than coarse manure. On light soils the plant food is leached downward in the soil to the crop roots.

FIG. 132. Unloading manure in small piles undesirable. These spots of tall buckwheat in Canada represent the small piles in which manure was unloaded. Usually the crop on these spots is so rank that it lodges before maturity and seldom produces a full crop of grain. (*E. Van Alstine.*)

If manure is plowed down deeply on these soils it may be out of reach of the roots, especially as the soluble part is leached farther from the roots.

Tonnage of Manure to the Acre. Farmers are keenly interested in the quantity of manure to use to the acre for different crops. Experience and ideas vary widely and should, because of variations in soils, crops, and in the manure itself. On the basis of the writer's contacts with thousands of farmers, it appears that their usual applications are too heavy to give the best results from their supply of manure. Much experimental work has been done on rate of use for manure. Typical effects from the application of different quantities to the acre are indicated in Table 23.

TABLE 23. EFFECTS ON YIELDS OF DIFFERENT RATES OF APPLICATION OF MANURE*

Manure, rate of application	Potatoes (average for 30 years), bushels		Wheat (average for 29 years), bushels		Clover (average for 27 years), pounds	
	Yield	Increase per ton	Yield	Increase per ton	Yield	Increase per ton
4 tons.	132.7	6.00	32.2	1.50	4,186	198
8 tons . . .	142.7	4.30	34.0	1.06	4,568	156
16 tons	170.3	3.22	34.9	0.61	5,145	103

*THORNE, C. E., and Staff, The Maintenance of Soil Fertility, *Ohio Agricultural Experiment Station Bulletin* 381, pp. 329–330, 1924.

These results show that low rates of application give larger returns for each ton of manure than heavy ones. With each crop the increase in yield per ton of manure is greatest for the lower rates. If the quantity of manure is large for the acreage, make heavier applications. If the quantity of manure available is approximately average, however, make moderate applications at frequent intervals; they produce larger returns than heavy ones at long intervals. In other words, 16 tons of manure on 2 acres produces more increase in yields than 16 tons all on 1 acre.

Rate-of-use data might be cited from a number of experiment stations; in all of them the lighter rates produce the larger increases per ton of manure. Put manure on frequently. This gives better results than using it with many years between applications.

The rates of application suggested for average conditions are given in Table 24.

TABLE 24. SUGGESTED RATES OF USE OF MANURE FOR AVERAGE FARM CONDITIONS

Crop	Tons of Manure to the Acre
Corn and wheat. . . .	8 to 10
New meadow seedings Alfalfa. . . . . Pasture. . . . . . . Grasses for hay. .	8 to 10 or less
Potatoes (not recommended)	12 to 15 if used
Apples	10 to 12
Beans (dry)	8
Tobacco and vegetables	10 to 20 as available
Cabbage	12 or more
Sugar beets (put on the year before beets)	6 to 8

If manure is plentiful, use somewhat heavier rates than these. If manure is scarce, use lighter applications, because this pays better than using all of the supply on part of the crop acreage and none on the rest. An exception may be made with vegetables because they need manure and because they make good returns for it. Vegetables, therefore, may well be manured even if none is left for meadows or pastures. Rate of use for vegetables will vary somewhat with the kind of vegetable. Leafy ones make better use of it than those that are grown for ripe seed such as tomatoes, peppers, and dry beans. The cabbage (leafy crops) family can use relatively large quantities of manure to advantage.

6. Making Artificial Manure from Straw, Leaves, and Leftovers

On vegetable and grain farms more manure than is usually available could be used advantageously. Such materials as straw, corn, cotton, and broomcorn stalks, cane pomace, and any similar materials that have no market value in the immediate situation can be made into valuable manure. Straw is not of much value, as such, on the strictly grain farm, but it can easily be made into valuable manure. Animals break feeds down in part during the digestive process. After manure is made, the decay organisms in it carry the change still further. In the straw pile, decay organisms do all the work.

In his work in Missouri, Albrecht[1] used approximately 70 pounds of sulphate of ammonia, 20 pounds of 20 per cent superphosphate, and 60 pounds of limestone to the ton of straw. These materials were mixed with the straw at threshing time. Now that much grain is harvested with the combine, a different method is called for. If there is a new seeding in the grain, remove the straw for best results and to avoid mixing it with the following year's hay crop. If that is done, the decay mixture can be added as the straw is piled for rotting. Lay down a layer of a few feet of straw and scatter the above quantity of the mixture over it. Succeeding layers of straw and mixture may be added.

Straw is so high in carbon that it does not decay readily of itself. Additional nitrogen is needed to enable decay organisms to accomplish their work quickly and without too great a loss of organic

[1] Albrecht, Wm. A., Artificial Manure Production on the Farm, *Missouri Agricultural Experiment Station Bulletin* 258, 1927.

matter. Using phosphorus (and some workers add potash also) is helpful. Limestone is used to correct some of the acidity that develops in the process of rotting. Too high a degree of acidity stops the decay, much as acidity checks fermentation in the silo. Wherever the rainfall is around 35 or 40 inches, sufficient water is present to keep the straw moist enough for rotting. Decay requires from 2 to 5 summer months.

If the straw is left on the land, from 100 to 200 pounds of sulphate of ammonia or a similar quantity of nitrogen in manure or other carrier of fertilizer nitrogen is needed. Manure, however, will probably be of greater service on other land. Unless nitrogen is used, the organisms take the nitrogen they must have from the soil. The crop then cannot obtain the nitrogen it must have for normal growth. Turning under much straw or similar coarse material low in nitrogen usually delays the growth of crops. After decay is nearly complete, nitrogen is again released and crop growth can be resumed. It is far better to apply the needed nitrogen than to risk the delay of the crop.

The leaves from shade trees about homes in the country, village, or city contain valuable organic matter and plant food. They, like straw, can be changed to manure in order to make good use of them.

Likewise, the small-home owner or gardener may utilize leaves and other coarse leftovers from vegetables or flowers. A mixture of 12 parts of sulphate of ammonia, 6 of superphosphate (20 per cent is good), 5 of muriate of potash, and 10 parts of limestone was suggested in *Hoard's Dairyman* (August 21, 1942). Use 1 pound of this mixture with 12 pounds of leaves or other waste materials. Green vegetable wastes decay without treatment because they are not too low in nitrogen. In place of this mixture, any good garden or lawn fertilizer gives good results. For a tramped bushel basketful of leaves or other material, the addition of 1 pint of fertilizer and 1/4 pint of limestone has proved entirely satisfactory. Wet down the leaves to prevent their being blown about. Pile them inside a circle of chicken wire or other suitable container. Wetting down without waiting for rain simply starts decay sooner.

With many of these ways of handling, some of the straw or leaves on the outside of the pile dries out and fails to rot. Stirring the pile is unnecessary, but a somewhat more uniformly rotted manure will result if the pile is mixed once or twice during the summer. An important point is that these organic materials should be used and

never wasted. Mineral soils nearly everywhere need additions of organic matter for best growth of crops.

7. Determining the Dollar Value of Manures

What is the dollar value per ton of manure? This is a question that is often asked. No one dollar value holds under so many different conditions. Its value is different from that of lime or fertilizer. With dairying, in particular, manure must be taken away from the barn daily or at least frequently. The necessity of taking it away is involved, perhaps, ahead of possible returns from its use. Properly used, manure increases crop yields. A ton of manure, therefore, is worth the dollar value of that increase in yield standing in the field where the crop grew. The cost of hauling and spreading may be deducted, although this does not necessarily follow because manure must be taken away from dairy barns. In figuring the returns from manure, long-time increases in yields rather than those from a single year are best. *Consistent use of manure improves the nitrogen and organic content, the water-holding capacity, and the tilth of the soil.*

Stevenson, Brown, and Foreman[2] found the average value of farm manure in a 4-year rotation in Iowa to be \$1.97 a ton; the range in value was from \$0.97 to \$3.84 a ton.

Wiancko, Walker, and Mulvey[3] report a value over the rotation on an average for 12 well-distributed stations of \$2.70 a ton. Field value of crops, not market prices, gives a correct picture. Average increases and average crop values for a 10-year period are better than those for a single year. The entire rotation and not the manured crop alone should be considered because of the residual effects of manures. From \$1.00 to \$2.00 a ton may be considered fair values for manure under normal price conditions.

SUMMARY

1. Farm manure is a valuable by-product of animal farming. The number, kind, and age of animals and the work done by them largely determine the quantities of manure that are produced. Feed and the quantity of bedding used are other factors.

[2] Stevenson, W. H., P. E. Brown, and L. W. Foreman, The Economic Value of Farm Manure as a Fertilizer on Iowa Soils, *Iowa Agricultural Experiment Station Bulletin* 226, 1926. Crop values from *Iowa Yearbook of Agriculture*, 1922.

[3] Wiancko, A. T., G. P. Walker, and R. R. Mulvey, Manure Increases Farm Income, *Indiana Agricultural Experiment Station Bulletin* 398, 1935. Crop values used: corn 55, oats 35, and soybeans 90 cents a bushel; hay \$8.00 a ton; straw and stover not evaluated.

2. Young animals and milking cows retain more phosphorus and nitrogen than do working animals utilizing mainly energy from their feeds.

3. Cow and pig manures are high in water content and are called "wet" or "cold" manures. Horse, hen, and sheep manures are drier than cow and pig manures and are, therefore, called "dry" or "hot" manures. Being drier they decay and heat up more quickly than cow and pig manures.

4. There is a striking similarity in the quantities of dry matter produced annually per 1,000 pounds of live weight by these animals.

5. Milk cows produce approximately 9 tons of manure, including bedding, during a barn-feeding period of 7 months—or about 8 tons in 6 months.

6. On the average, mixed manures contain approximately 10 pounds of nitrogen, 5 pounds of phosphoric acid, and 10 pounds of potash to the ton of ordinary moist manure. Manure, therefore, is distinctly dilute in comparison with fertilizers.

7. The liquid part contains much of the nitrogen and potash in manures. Because the plant food in the liquid part becomes available to crops readily, it is of high value and ought to be carefully saved. Absorbing it in bedding is a good way to save it.

8. Dried manures are relatively low in water and are, therefore, much richer in plant food than wet manures.

9. Farm manures are dilute, bulky, and variable; being full of decay organisms, they rot quickly in warm weather. Losses are heavy from manure stored in open piles. Much of the organic matter, nitrogen, and potash is lost from hot manures and from those kept in open piles during the warm months. Lower losses take place in cold manures.

10. The value of manure may be conserved: (1) by hauling it to the field daily as it is produced; (2) by protecting it from rain and snow; and (3) by keeping it compact and moist. This may be accomplished by storing it in a deep pile (if not hauled out on the land) or letting young stock run over and trample it.

11. In using manures, bear in mind that they are relatively low in phosphorus, and most crops respond to additions of this element. This is particularly true of grain crops.

12. Use superphosphate in the stable, on the spreader load, or on manured land to reinforce the manure.

13. Frequent use of 8 to 10 tons of manure an acre produces larger increases in yield of feed crops than twice as much manure applied half as often. A good rate of application on many crops is 8 to 10 tons of manure per acre.

14. Putting on manure with a spreader is the easiest way, and this method gives excellent results.

15. Straw, leaves, and other coarse materials may be rotted down into

valuable manure by adding small quantities of fertilizer materials and a little limestone (page 242). The material should be decomposed and ready for use in from 2 to 5 months. Straw and stubble, as left by the combine, if not needed for bedding may be left on the land, and nitrogen equivalent to 100 or 200 pounds of sulphate of ammonia may be added to it to decompose the straw. Leaves from shade trees in town may readily be converted into valuable fertilizer for the vegetable garden or the flower beds (page 243).

16. The dollar value per ton of manure is difficult to determine because of wide fluctuation in crop values from decade to decade. Fair values under normal prewar prices were \$1 to \$2 per ton.

10. Growing and Using Green-manure Crops

THE number of tractors used on farms decreases the need for horses and mules. As the number of work animals decreases, so also does the supply of manure. There is compensation, however, in that, on the whole, dairy cows and other animals may use the roughage formerly fed to work animals. A shift to food crops away from hay and other feed crops works in the same direction as reducing the number of work animals. The native, or original, organic matter in the soil has been reduced during the years of cropping. The need for manure or a substitute for manure is very definite on much of the longer-cropped areas of the world. A good substitute for animal manures are green crop materials. Such materials as are produced for the purpose of mixing (in the green state) with the soil are called *green manures* or *green-manure* crops.[1] Crops that are grown primarily to provide protection for the soil are termed *cover* crops. Many cover crops are plowed into the soil before they mature and are, therefore, green manures.

A distinction between green-manure and cover crops, however, is unimportant. The point of real consequence is that organic matter be added to the soil often and in fairly large quantities to the acre. As with animal manures, moderate quantities to the acre added to the soil frequently give best results. It may well be stated here that building the organic matter up to a high level in soils is difficult if not impossible. Frequent additions tend to maintain a revolving supply of fresh organic matter. The supply of soil organic matter is something like a bank account. Regular checking on an account that does not receive deposits soon overdraws the account. So it is with the soil; if organic matter is not returned at fairly regular inter-

[1] PIPER, C. V., and A. J. PIETERS, Green Manuring, *U.S. Department of Agriculture, Farmers' Bulletin* 1250, 1922, and PIETERS, A. J , "Green Manuring," John Wiley & Sons, Inc., New York, 1927, supply additional information on this topic.

vals, cropping after a few years exhausts the plant-food supply. The account is overdrawn. In both cases regular "deposits" are essential.

Green-manure crops can be grown to advantage in the South and wherever there is time for their growth in addition to that needed for the regular crop. In some instances, green manures are grown in place of a cash crop. Generally, however, green-manure crops occupy the land before, after, or between the regularly grown crops.

Legumes probably possess some advantages over nonlegumes. They can fix some nitrogen when there is sufficient time for it. Annuals and winter annuals cannot be expected to do much, but the biennials, given enough time for growth, do fix considerable quantities of nitrogen. Peas and beans represent annual legumes; hairy vetch, the winter annuals, and ordinary sweet clover the biennials. Inoculation of the seed of legumes before seeding is often necessary if they are to fix nitrogen. Probably the most important point about any green-manure crop is its ability to produce large quantities of green material for mixing with the soil. The growing and using of green-manure crops is discussed in this chapter under these headings:

1. Determining Benefits from Green Manures
2. Avoiding Undesirable Effects from Green Manures
3. Selecting Green-manure Crops
4. Growing Green-manure Crops
5. Using Green Manures

1. Determining Benefits from Green Manures

Most green-manure crops follow crops that have been well fertilized. Then the green-manure crop requires no additional fertilization, and, moreover, the green-manure crop takes up for its use plant food that would otherwise be lost by leaching away (Fig. 133). When the green material is plowed in, the plant food is soon released to the succeeding crop. On soils that are not heavily fertilized, green-manure legumes may fix appreciable quantities of nitrogen.

Generally speaking, leguminous material (Fig. 134) is higher in nitrogen than nonleguminous material. Leguminous material stimulates the process of decay and the preparation of plant food for crops. For this reason, leguminous crops deserve a place in mixture with nonleguminous ones in green-manuring systems. Nonleguminous crops that are plowed in during their immature condition decay

FIG. 133. A cover of wheat on muckland. A growth like this absorbs and holds plant food against leaching, and prevents blowing, and the roots hold the soil together after it is plowed.

FIG. 134. Sweet clover in wheat. In some parts of humid sections biennial white sweet clover may be sown in the spring and a good growth obtained. This crop was photographed on August 19 in western New York.

quickly. In fact, green material often disappears in a few days. But leguminous or nonleguminous organic matter should be returned to the soil.

Although space does not permit a full discussion of green manures,

a few examples of the benefits produced may be given in addition to setting forth some of the underlying principles.

To Crops. The yields of many crops are increased by the consistent use of green manures. The addition of fresh green material seems to activate the soil organic matter in a way that benefits crops. Of the large amount of experimental work that has been done, that from Georgia with corn and cotton is selected as representing what can be done with green manures. In this work vetches, winter peas, and rye were compared with check plots that had no green-manure crops. The yields are given and the fertilization is shown in Table 25.

TABLE 25 YIELDS OF COTTON AND CORN FOLLOWING LEGUMES AND RYE*
(7-year average)

Green-manure crops	Seed cotton per acre, pounds		Corn per acre, bushels	
	Series II 3-9-5 fertilizer	Series I 0-9-5 fertilizer	Series II 2-10-4 fertilizer	Series I 0-10-4 fertilizer
Austrian winter peas	1,199	1,233	52.7	57.1
Monantha vetch	1,305	1,064	50.3	48.0
Hairy vetch	1,215	961	50.4	46.9
Rye	1,167	956	38.4	34.1
No green-manure crop	913	690	39.7	37.9

* ALEXANDER, E. D., Austrian Winter Peas and the Vetches, *Georgia Agricultural Extension Bulletin* 453, p. 4, 1935.

The same quantity of fertilizer was used for cotton on all plots of Series I. For comparison to determine the effect of nitrogen from the legumes, the same quantity of phosphorus and potash was used without nitrogen on Series II. Similarly, the nitrogen was left out of the fertilizer on one series of corn plots.

All treatments increased the yield of seed cotton. Austrian peas and Monantha vetch give the best yields without fertilizer nitrogen. With nitrogen applied, the yields were higher for all green-manure treatments. Austrian winter peas (Fig. 135), preceding cotton without fertilizer nitrogen, produced a slightly higher yield of cotton than the peas did with nitrogen. This difference, however, is within experimental error. The peas gave 4.4 bushels more corn than did nitrogen. With the other green-manure crops, however, nitrogen in the fertilizer increased yields. Of these green manures, the Austrian

winter pea was clearly the best one. Under these soil conditions in Georgia, rye improved yields of cotton to an extent that undoubtedly was profitable. The yield of corn, however, was lower with than without rye, even on the corn that received nitrogen in the fertilizer. The loss, however, was only 1.3 bushels of corn to the acre, and this slight difference is not significant. It is not enough to be accepted as proof that the difference was caused by the difference in treatment of the soil.

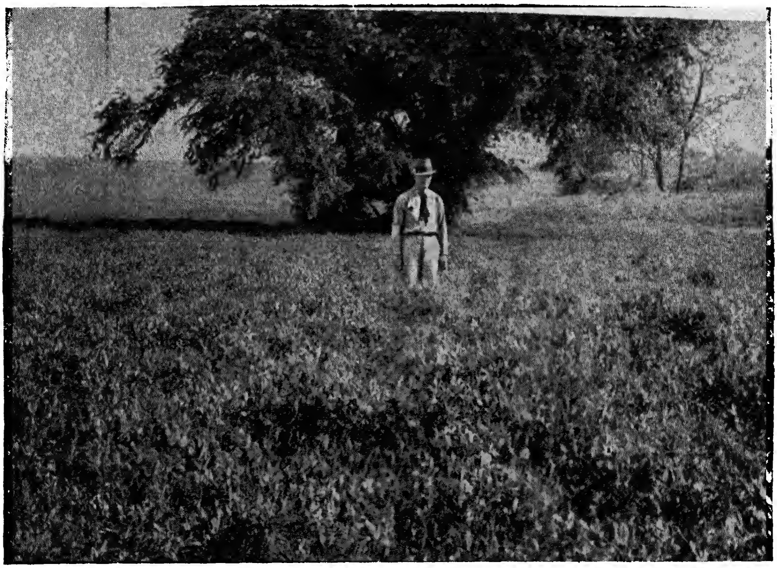


FIG. 135. Austrian winter peas in Oklahoma. This crop is well adapted for the warmer part of the country, where it is widely used. (*U.S. Soil Conservation Service.*)

To Soils. All of the effects of green manures, properly managed, are beneficial to the soil. The organic matter turned under has temporary effects on the soil. There is but little addition of permanent organic matter to soils from green manures. Nevertheless, they do add to the supply of very active, but temporary, organic matter.

2. Avoiding Undesirable Effects from Green Manures

Plow under green-manure crops and mix them with the soil as truly green material or before they approach maturity. Overmature, nonleguminous material requires additional treatment. Rye or other

grain that has headed and has begun to turn yellow is coarse and stiff and holds the soil loose so that it dries readily. Moreover, the rye at that stage is high in carbon and low in nitrogen. To bring about its decay the organisms must have additional nitrogen. Unless from 20 to 40 pounds of nitrogen in fertilizers are put on with the rye, the organisms take the nitrogen they need from the soil. This checks the early growth of the main crop and may reduce the yield unless it

FIG. 136. The blue lupine. This summer-growing legume is useful where it can have a period of warm weather for its growth. (*P. H. Wessels.*)

has been adequately provided with nitrogen. After a time, nitrogen again becomes available for the crop. Growth however, has been delayed, and probably the yield has already been reduced. From the standpoint of holding moisture for the crop, roll the soil down well after plowing in overmature rye or other coarse plant materials, especially low-nitrogen ones.

3. Selecting Green-manure Crops

A wide range of plants serve well as green-manure crops. To be a *best* green-manure crop, the requirements are (1) *a plentiful supply of seed at a reasonable outlay to the acre;* (2) *that the plants are not exacting in the requirements of soil and of plant food;* (3) *that they are useful over wide areas;* (4) *that they are capable of producing large quantities of both root and top growth;* and (5) *that they can grow well in the cooler parts of the season.* The reason for this is that the main crop uses the best part of the growing season.

Although, as pointed out earlier, leguminous green-manure crops may fix nitrogen under favorable conditions, this advantage is often balanced more or less by the higher cost of seed for leguminous green manures (Figs. 136 and 137). Some crops thrive in the cool part of the season and others only in the warm part of the growing period. In the following tabulation are given the names of green-manure crops, the time of year they thrive, and the section in which they are most useful.

CROPS USEFUL FOR GREEN-MANURING PURPOSES

For the Cooler Part of the Year

Name	Section
Legumes	
Austrian winter pea	South, generally
Hairy vetch	Wide North-South range
Smooth vetch	South, generally
Woolly-pod vetch	South, generally
Crimson clover	South, northern part
Monantha vetch	South, southern part
Tangier pea	South, southern part
Southern bur clover	South, southern part
Tifton bur clover	South, southern part
Nonlegumes	
Rye	Over a wide territory
Wheat	North and southward
Winter oats and barley	South and somewhat northward
Rye grass	Wide range
Summer	
Legumes	
Alfalfa	In Western orchards
Red clover	Wide range, North
Sweet clover	Wide range
Cowpea	South and southern Middle West
Soybeans	Wide range
Common Sesbania	Southwest
Lespedeza	South to southern Middle West
Crotalaria	Lower South
Florida beggarweed	Lower South
Deering velvet bean	South
Canada field pea (spring)	Wide range
Nonlegumes	
Oats, barley	Wide range
Spring wheat	Wide range
Sudan grass	Wide range
Millets	Wide range
Pearl millet	Wide range
Buckwheat	Wide range
Rape (fall)	Wide range
Corn	Wide range
Cowhorn turnip	Wide range

FIG. 137. Canada peas and oats. This spring-sown mixture may be plowed down for such late-planted crops as cabbage and cauliflower or for fall-seeded crops.

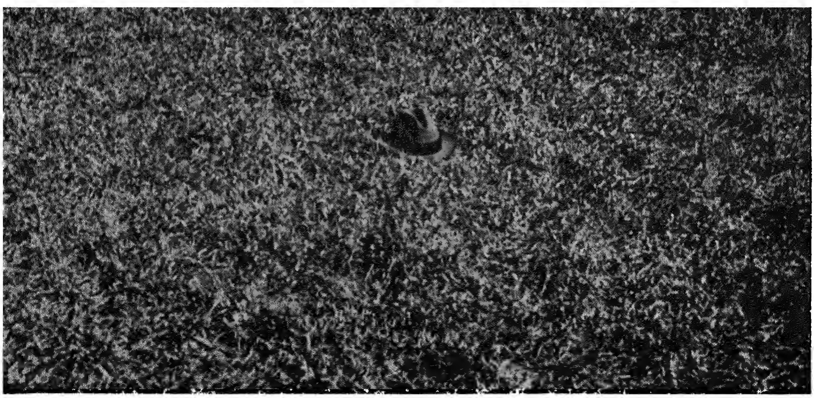


FIG. 138. Rye and spring barley on Long Island, New York. An early spring view of the previous autumn growth. The light-colored material is the dead barley. The rye had begun spring growth. Such a growth takes up and holds plant food against loss, covers and protects the soil over winter, and supplies fresh, active organic matter to the soil on being plowed in.

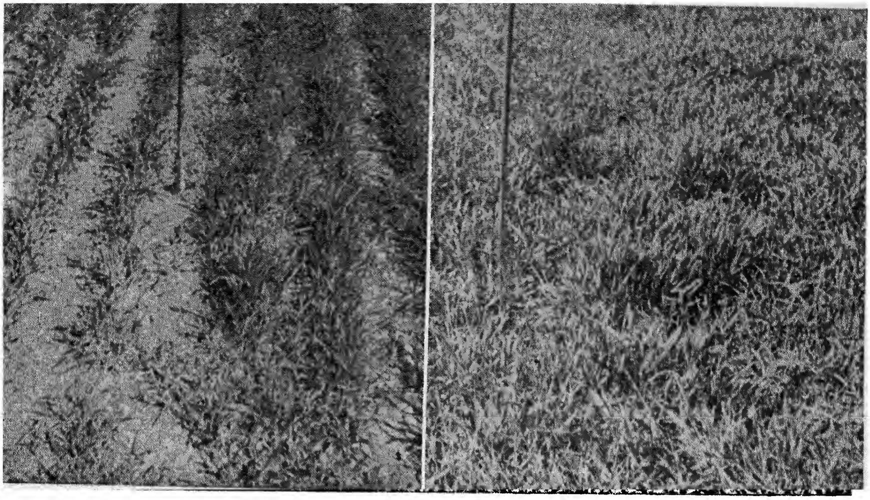


FIG. 139. Better cover from broadcast rye. At left, drilled rye, at right, broadcast rye. Broadcasting gives much better protection to the soil.

FIG. 140. Overmature rye. Because this rye has made its maximum growth, it is coarse and high in carbon. Nitrogen must be added to decay it quickly. Otherwise decay robs the crop of nitrogen from the soil.

The plants in this list are used for cover and green-manure crops. They vary in their soil and climatic requirements and in the cost of establishing them. No specific recommendation can be made for large areas. Rye (Figs. 138, 139, and 140) is more widely used than any other crop. Millets are objectionable if their seeds are allowed to mature, for they then become weeds in clean-cultivated crops that follow.

Orchards are different with respect to the production of seed. In them, lespedeza, rye, buckwheat, grasses, and sweet clover may be allowed to seed. Once they have seeded, they maintain a cover under controlled conditions and seldom require reseeding. This lessens the expense of protecting the soil and of producing organic matter for the soil.

4. Growing Green-manure Crops

Usually only small outlays of cash are made directly for green-manure crops. Considerable effort has been made to return organic matter to lands that produce high-return crops such as vegetables, fruits, seed crops, and nursery stock. Attention to the acidity of the soil is needed. If the main crop is sensitive to acidity, the soil will be limed, and lime-loving green-manure crops may be grown. If, on the other hand, the crop requires moderate acidity, it will be necessary to use green-manure crops that are tolerant of that degree of acidity. If the main crop is heavily fertilized, even though the soil is moderately acid, green-manure crops that are sensitive to acidity may be expected to make good growth. Unless there is a goodly residue of fertilizer, applications of phosphorus are needed by legumes. They require a high phosphorus content and pay well for its use. The outlay for green manures is based on the probable returns they can produce in the crops that follow. Green manures in a feed-crop system will ordinarily receive little direct fertilization. For vegetables, in contrast, considerable outlay for seed and fertilizer for green-manure crops can be made with profit.

Fertilizing Green-manure Crops. If a green-manure crop follows a heavily fertilized crop, the use of fertilizer is usually not necessary. With light fertilization, as with many feed crops, however, use fertilizer direct for the green-manure crop in order to obtain good growth. An example of this condition is found in the North. Domestic rye grass is seeded at the time of the final cultivation of field corn

and sweet corn. The corn is usually fertilized only moderately. Not much readily usable plant food is available to the rye grass. To get a quick start under such conditions and to obtain cover quickly and a large fall growth, apply 200 or 300 pounds of any good fertilizer. This treatment starts the grass off quickly in the excellent growing weather that usually prevails at that season. Even as far north as central New York, a thick growth several inches tall is obtained before the end of the growing season. The grass starts to grow early in the spring and produces a good yield before time to plow it in for the succeeding crop. In favorable seasons some pasturing can be done if desired. The equivalent of 1 ton or more of air-dry hay may be expected under favorable growing conditions. In a dry summer and an early fall, less growth will be produced. On the average, however, a good overwinter cover is produced and the soil is well protected against erosion by either wind or water. Some plant food that might have been leached out of the soil has been absorbed and held by the grass. After the green material has been mixed with the soil, the plant food in it is quickly released for the benefit of the crop. What may have been seeded mainly as a cover crop for protecting the soil is finally plowed in as a green-manure crop. Thus, both the following crop and the soil are benefited by the growth of the rye grass.

Seeding Green-manure Crops. The usual seeding rates for grains are satisfactory, but if the period for growth is short a better cover is produced by a heavier seeding. Rye and winter wheat are used at rates of 6 to 8 pecks to the acre; oats and barley, either mixed or separately, 8 to 10 pecks to the acre. Unusually small-seeded varieties will be sown at the lower rates. If hairy vetch is sown with winter wheat or rye, 2 pecks of it are used with from 4 to 6 pecks of the grains. For other green-manure crops, the usual rates for grain, or a little heavier, are satisfactory. The grasses and other small-seeded crops grown need a heavy rate of seeding if they are to produce goodly quantities of organic matter in the short time that is usually available for growth.

Fitting Green-manure Crops into Cropping Systems. Green-manure crops are generally worked in between money crops, either of a single year or over a rotation. The cool part of the spring before hot-weather crops are started and the late summer and fall after the midseason crops have been harvested are the main times for the production of green-manure crops. If grain is grown in rotation with

potatoes, beans, or cabbage in the North, sweet clover may be sown in grain. Wheat or winter barley are harvested early enough for sweet clover to make considerable growth.

Rye or spring oats may be sown for plowing-in for crops that are planted early in the spring in the North. In the South, grow rye, winter oats, winter barley or Austrian winter peas to plow in for the earlier spring crops. For midsummer crops, use early-sown spring

FIG. 141. Oats in sweet corn. The oats were seeded about mid-September in New York. A growth of about 6 inches had been made up to the time this picture was taken. Oats serve the same purpose as rye in the fall, but they are winterkilled and make no spring growth. This may be an advantage under some conditions but is a disadvantage under others.

grains and Canada field peas. These crops should make worth-while growth before time to plow for midsummer crops. The fall-sown crops are preferable even for midseason crops because they protect the soil over winter. If this is to be done it will probably pay to include winter peas or one of the vetches. They would be expected, if inoculated, to fix some nitrogen during the spring growth. Rye, oats (Fig. 141), barley, or wheat can be sown in many crops in early fall for plowing into the soil the next spring. Cost of seed will usually determine which of these crops to use.

Because of the longer growing period in the South, and because growth is made in warm periods in winter and again in early spring, green-manure crops can be used to better advantage there than in the North. And because green-manure crops use water that may be needed for the main crop, the use of green manures is restricted during the growing season. The fall growth goes down onto the surface of the soil and there decays the following spring. A fine growth of winter cover crops is usually made in the spring before it is time to plow the land for the next crop, especially if it is a late one like beans or cabbage. The growth produced and the nitrogen fixed by sweet clover in this way at the Ohio Agricultural Experiment Station are shown in Table 26 (Fig. 134).

TABLE 26. YIELD AND NITROGEN CONTENT OF TOPS AND ROOTS OF SWEET CLOVER AT DIFFERENT DATES IN THE SEEDING YEAR AND THE YEAR AFTER SEEDING*

	Yield per acre (air-dry), pounds			Nitrogen per acre, pounds		
	Tops	Roots	Total	Tops	Roots	Total
Aug. 1	659	182	841	17	4	21
Aug. 15	963	310	1,273	28	9	37
Sept. 1	1,431	577	2,008	41	18	59
Sept. 15	1,544	884	2,428	48	27	75
Oct. 1	1,881	1,273	3,154	54	40	94
Oct. 15	1,714	1,721	3,435	44	56	100
Nov. 1	1,616	2,115	3,731	39	74	113
Development in the year following seeding						
Apr. 1	420	2,130	2,550	19	92	111
Apr. 15	690	1,750	2,440	29	73	102
May 1	1,930	1,360	3,290	75	49	114
May 15	3,360	1,280	4,640	110	37	147
June 1	4,940	1,200	6,140	133	29	162
June 15	6,030	1,110	7,140	142	24	166

* Handbook of Experiments in Agronomy, *Ohio Agricultural Experiment Station Special Circular* 53, p. 47, 1938.

In low-rainfall areas, because of the reduction in the organic-matter content of the soil and the increasing shortage of animal manures, the production of organic matter to return to the soil is gaining in importance. Sometimes it is advisable to take a whole season to produce organic matter. For this purpose, there is a much

wider choice of crops to grow. The biennial or perennial legumes and hot-weather annual legumes may be grown to excellent advantage. The longer-lived legumes fix more nitrogen for return to the soil than do the annuals. Long-lived grasses may be used, as may also such annuals as millets, Sudan grass, corn, pearl millet, and others.

In all returns of organic matter to the soil, keep one cardinal principle in mind. Trying to maintain a high level of active organic matter in soils is difficult and expensive. As with manure, moderate-sized, frequent returns of organic matter are more profitable than large applications that are made many years apart.

5. Using Green Manures

The management of green manures with respect to the time of planting the main money crop for the year requires consideration. Immature green material decays quickly in moist warm soils. Green sweet clover decays completely in 10 days under favorable conditions. Because of its high nitrogen content, leguminous material in general decays quickly in warm soils. Strictly fresh green rye as well as other grains and grasses also decay quickly under favorable conditions. Grains that have headed out, especially if they have begun to ripen, must be managed right; otherwise, injury rather than benefit to the following crop is the result. It may be better to take off a fairly heavy crop of rye that is headed than to turn it under without adding nitrogen. If it is turned under, from 20 to 40 pounds of nitrogen are needed to help in its decomposition. Because rye has drawn heavily on the moisture of the soil, the land should be rolled down to compact it thoroughly. Otherwise the stiff straw holds the soil in a loose condition that dries out easily. The germination of the succeeding crop is delayed and a reduced yield is the result. It is far better to plow down green-manure crops somewhat early than to risk excessive drying of the soil. Sweet clover, red clover, and other legumes also draw heavily on the soil moisture during their active growth. It is undesirable to plow them down, fit the seedbed, and plant a crop at once. If rain comes very soon, good results are obtained. If rain is delayed, the soil may dry out so that corn does not germinate until weeks later. The result is a poor stand and usually a reduced yield. It is better to plow down the green material 10 days to 2 weeks before time to plant the main crop. If it is impossible to plow, the drain on

the soil moisture may be checked by double-disking to kill the green-manure crop. It should then be plowed in as soon as possible.

In the space available it has been possible only to state, with a few examples, the underlying principles of green manuring. Many of the state extension services publish bulletins on the use of green manures locally. Consult these publications for the details of local application of these general principles.

SUMMARY

1. Maintaining the organic content of soils is essential. It is better to add it in green-manure and cover crops in moderate quantities often than in large quantities many years apart.

2. Adding active, fresh organic matter in green manures increases crop yields under favorable conditions.

3. Green-manure crops mixed with the soil produce all of the benefits of organic matter to soils.

4. As green manures, leguminous crops possess many advantages over nonleguminous ones. Some of the legumes grow at a time of year when they fix some nitrogen. Even if they fix no nitrogen, they decay more rapidly in the soil than do nonleguminous materials such as grains and grasses. This is more important with relatively mature than with fresh, green materials.

5. If for any reason rye or other nonleguminous green-manure crops become relatively mature and woody, add from 100 to 200 pounds an acre of sulphate of ammonia, or a similar quantity of nitrogen in some other fertilizer; this is needed to help in the decay of such material. If no nitrogen is added, following crops may suffer from lack of available nitrogen in the early part of the season.

6. Select the right green-manure crop. Be sure there is a plentiful supply of seed at a low price. Use crops that grow well without special treatment. Select those that make good growth in the cool parts of the season and that produce large quantities of organic matter. On page 253, green-manure crops are listed, along with the regions to which they are well adapted.

7. Fertilize green-manure crops moderately unless they make good growth on the residue of the fertilizer that was used on the main crop.

8. Seed at rates similar to or heavier than those used for grain or hay production. This is most important if overwinter cover is needed to protect the soil from erosion. Fit green-manures into the cropping system so as not to interfere with the production of the crops that produce income.

9. Because green-manure crops require much water, use caution in seeding them in dry areas lest they rob the main crop of the water it needs.

10. Heavy growths of green-manure crops should be plowed into the soil at least 10 days before seeding the main crop. Coarse or mature rye had better go into the soil 2 weeks or a little more, if possible, before seeding the main crop. With only a light growth, such as 3 to 6 inches of rye, seeding may follow plowing almost immediately, in the case of a crop like potatoes, tomatoes, or cabbage.

11. Selecting and Using Commercial Fertilizers

IN THE early days, ashes, fish, and slaughterhouse wastes were scattered on the land to get rid of them. Farmers observed that some crops made excellent growth where certain of these wastes had been spread. For example, ashes improved the growth of clover and other legumes. Fish and slaughterhouse products increased the growth of grasses. When used on grains, the slaughterhouse materials caused rank growth of straw that lodged badly in seasons of normal and heavy rainfall. Wastes that contained much ground-up bone produced less lodging and more grain in the heads, and generally improved other crops that produced ripe seed.

As farmers and gardeners bought and used these materials for their crops they came to be called *fertilizers*, and using them, *fertilization*.

Selecting and using fertilizers for growing crops are discussed under the following headings in this chapter:

1. Recognizing the Place Fertilizers Hold in Agriculture
2. Becoming Familiar with Fertilizer Terms
3. Controlling the Composition of Fertilizers
4. Comparing Fertilizer Materials
5. Determining the Effects of Fertilizer Elements
6. Manufacturing Commercial Fertilizers
7. Home-mixing Fertilizers
8. Purchasing Fertilizers
9. Using Fertilizers
10. Fertilizing Farm Fish Ponds

1. Recognizing the Place Fertilizers Hold in Agriculture

Fertilizers are used to supplement the plant foods which field crops are able to obtain from the soil. For vegetables and greenhouse plants, all the plant food these crops can use is often put on as fertilizer. Such crops do use plant food from the soil, but with heavy

fertilization they make rapid growth even under only moderately favorable conditions. Moreover, greenhouse crops are often grown under conditions that greatly restrict their root systems. Heavy fertilization, then, is necessary if plants are to make the desired growth.

The manufacture of fertilizers dates from about the middle of the 19th century, but only small tonnages were made and used at that time. As the agriculture of this country expanded, the demand for products increased and, because the more readily available plant food in the soil was used up, more fertilizer was needed. An industry that used mainly waste products at first expanded into what today is a giant, highly specialized chemical industry. The tonnages of fertilizer used in the United States over a 64-year period are given in Table 27.

TABLE 27. TONS OF ALL COMMERCIAL FERTILIZER USED IN THE UNITED STATES*

1880	1,150,000	1936	6,931,000
1890	1,950,000	1937	8,226,000
1900	2,200,000	1938	7,548,000
1910	5,453,000	1939	7,765,000
1920	7,177,000	1940	8,303,000
1930	8,222,000	1941	9,241,000
1931	6,354,000	1942	10,009,000
1932	4,385,000	1943	11,539,000
1933	4,908,000	1944	12,072,000
1934	5,583,000	1945	13,202,000
1935	6,276,000	1946	13,600,000
		1947	15,028,000

* *The Fertilizer Review*, Vol 20, Special Issue, p. 6, 1945.

The extremely rapid growth in the use of fertilizer during World War II is shown here. These figures indicate the ability of the present fertilizer industry to supply all the fertilizer that is needed for the domestic production of food and feed and some to spare for shipment to other parts of the world. American farmers used increased tonnages of fertilizer during the war because its cost was low in relation to the value of crops, and in order to produce large quantities of food for ourselves and our allies.

2. Becoming Familiar with Fertilizer Terms

Explanation of commonly used terms will help us to understand their use throughout the following discussion on the selection and use

of fertilizers. Among these terms are: *unit; guarantee; formula; analysis-grade; mixed fertilizer; drier* or *conditioner;* and *ratio.*

Unit. As used by the fertilizer industry, unit means 1 per cent in a ton, or 20 pounds. Rock phosphate and superphosphate have been sold on the basis of the guaranteed number of units of phosphorus or phosphoric acid to the ton. Similarly, tankage is marketed on the basis of the units of nitrogen it contains and potash salts on the basis of the units of potash the salts carry. A grain fertilizer that has 5 per cent of nitrogen, 20 per cent of phosphoric acid, and 5 per cent of potash contains 5 units each of nitrogen and potash and 20 units of phosphoric acid or 30 units in all. Knowledge of the unit idea is helpful in comparing fertilizers as well as in the marketing of such representative fertilizer materials as rock phosphate, superphosphate, tankage, and potash salts.

Guarantee. By guarantee is meant that the manufacturer states positively that the fertilizer actually does contain the percentages of plant food listed on the fertilizer bags or on tags that are attached to the bags. Nitrogen is given as per cent of *total* nitrogen, phosphorus as per cent of *available* phosphoric acid, and potassium as per cent of *water-soluble* potash in fertilizer or fertilizer materials.

Formula. The formula for a fertilizer is a statement of the amount of each ingredient or fertilizer material that was used in the make-up of a mixed fertilizer. The number of pounds of each carrier of nitrogen, of each carrier of phosphorus, of each potash salt, and of drier that is used in 1 ton of mixed fertilizer is stated on the fertilizer bags or tags. Sometimes the quantity of nitrate nitrogen used is given. Fertilizers for which this information is given are said to have an *open* formula. If none of this information is given, the fertilizer is called a secret- or closed-formula fertilizer. Most fertilizers are of the closed-formula type.

Analysis (Grade) of Fertilizers. The percentage of total nitrogen, of available phosphoric acid, and of water-soluble potash constitute the *analysis* of fertilizers. Fertilizers with an analysis of 8–16–8 contain 8 per cent each of nitrogen and potash and 16 per cent of phosphoric acid. Not many years ago, fertilizers with a total of less than 14 units of plant food were called *low*-analysis fertilizers and those with 14 units and more, *high*-analysis fertilizers. Today, fertilizers with less than 20 units are called *ordinary-analysis* fertilizers,

those with from 20 to 30 units, *high-analysis*, and those that contain more than 30 units to the ton are spoken of as *concentrated* fertilizers. The latter are so easily made that those which have many fewer units are not economical for the user. Fertilizers with 40 and even as high as 60 units are on the market. Several states prohibit the sale of fertilizers that contain less than 16 *units* of plant food. The other states should follow. With the developments that are expected, these higher analyses may soon become the ordinary-type fertilizer. Recently, the term *grade* has been used instead of *analysis*.

Mixed Fertilizers. Mixed fertilizers contain several separate ingredients that have been mixed to make a particular analysis. A mixed fertilizer that contains nitrogen, phosphoric acid, and potash is called a *complete* fertilizer. One that has only two of the fertilizer elements, such as phosphoric acid and potash, is sometimes called an *incomplete* fertilizer.

Drier, or Conditioner. Certain fertilizer materials readily absorb moisture from the air if the humidity is high. The term *deliquescent* is used to describe this kind of material. If one or more deliquescent materials are used in a mixture, lumping may result. To keep home-mixed fertilizer in good drilling condition, certain organic materials are introduced that absorb moisture in the mixtures. These organic materials are termed *driers*, or *conditioners*. Such organic materials as tankages, seed meals, peat, and calcium cyanamide are good driers. For this reason, nitrogen in these materials costs more per unit than it does in inorganic carriers of nitrogen.

Ratio. In the period immediately before World War II, a large number of different fertilizer analyses, or grades, were on the market. As an aid in classifying them, the term ratio was developed. The 4–8–4 fertilizer has long been a favorite analysis with vegetable growers. It contains only 16 units of plant food. With the coming of high-analysis carriers of plant food came a demand for more concentrated mixtures. Growers, however, wished to have the same relationships between nitrogen, phosphoric acid, and potash as in the 4–8–4. This led to the mixing of the 5–10–5, and later of 8–16–8, 10–20–10, and even 15–30–15. All of these fertilizers have one thing in common; dividing the analysis through by the percentage of nitrogen gives the ratio 1–2–1, (4–8–4 ÷ 4 = 1–2–1). Similarly, 10–20–10 ÷ 10 gives 1–2–1; 1–2–1, therefore, is the ratio for all of

these fertilizers. In other words, each analysis contains twice as many units of phosphoric acid as of nitrogen or potash.

All fertilizers of a given ratio are equally desirable for any one crop, insofar as plant food is concerned. A ton of 4–8–4 contains 80 pounds of nitrogen; 1,600 pounds of 5–10–5, or 800 pounds of 10–20–10, carry 80 pounds of nitrogen and the same quantities of phosphoric acid and potash as a ton of 4–8–4. If it were planned to use ½ ton of 4–8–4[1] to the acre for a vegetable crop, 800 pounds of 5–10–5 or 400 pounds of 10–20–10 would supply the equivalent in plant food to the acre. Instead of a long statement like those just made one might say, "Use 800 pounds an acre of 5–10–5 or the equivalent in any fertilizer that has the 1–2–1 ratio." Or perhaps simpler still: Use 160 pounds of plant food in a 1–2–1 ratio. It would not matter which analysis is used; one supplies the required quantity of plant food the same as another. Fertilizer ratio is much used in discussions of the fertilization of crops.

3. Controlling the Composition of Fertilizers

In the early development of fertilizers they were sold as potato, corn, cabbage, or wheat fertilizers. Later, these became "potato special" or "bean special." Even recently the same analysis has been sold as the particular *special* for several different crops. Of course, the make-up of these *specials* might have varied, but probably it did not.

In the early days, control of the composition of fertilizers did not rest on the taking of many samples and the making of many chemical analyses as it does now. Quick, accurate methods of analysis were unknown then. Probably most manufacturers intended to put the plant food called for in the analysis into the bag, but simply could not because of variations in the composition of the materials mixed. Possibly lack of response of his crops to fertilization led the farmer to think that some scarce ingredient had been *stretched* too much in order to satisfy the growing market for mixed fertilizer. Whatever the cause, the states were asked to establish fertilizer control and it was well understood that the reliable manufacturer as well as the farmer was protected by fertilizer-control laws.

[1] Each 100 pounds of 4–8–4 fertilizer contains $4 + 8 + 4 = 16$ pounds of plant food. Then: ½ ton of 4–8–4 contains 16 pounds $\times$ 10 (hundreds) = 160 pounds of plant food. 800 pounds of 5–10–5 contains 20 pounds $\times$ 8 (hundreds) = 160 pounds of plant food. 400 pounds of 10–20–10 contains 40 pounds $\times$ 4, (hundreds) = 160 pounds of plant food.

Practically all the states now have fertilizer-control laws on their statute books. The manufacturers pay a tax to support the control work. In the Southeast, the tax takes the form of a definite amount on each ton of fertilizer sold by each manufacturer or mixer. In New York the tax is $20 a year for each analysis registered for sale in the state by each fertilizer company. Whether a few tons of fertilizer or many are sold during the year, the tax is $20 for the 12-month period. The tonnage tax appears to be fairer for the small producer. It has the advantage that the state control agency has definite information at the end of the year as to how much of each analysis, or grade, of fertilizer was sold by each producer, and, therefore, the total quantity sold during the year in the state.

The usual requirements for registration are for each manufacturer or selling agent to give: (1) his principal address; (2) the brand, name, or trademark under which a fertilizer is sold; (3) the guaranteed analysis; and (4) the net weight of fertilizer in the bag or package.

To learn how well actual analyses check with the guaranteed analyses, a system of inspection is maintained by the states. The inspectors drop in unannounced in a dealer's warehouse and take samples out of the bags that are on retail sale, or possibly on their way to the farm of the ultimate buyer. These samples are numbered, sealed, and sent to the laboratory for analysis without further identification. Finally, an annual bulletin is published that shows the analysis as found by the state's chemist, along with the manufacturer's guarantee and his name. This kind of publicity is good or bad advertising for the fertilizer producer—good if the *found* analysis is higher, especially for nitrogen, than the *guaranteed* analysis. The latter is given on the bag.

If a producer's found analyses are above his guarantee, his salesmen point to it with pride; if the found analyses are below the guaranteed ones, his competitors are in a position to "point with pride," provided, of course, that their own skirts are clean. For these reasons no reputable producer will knowingly permit his "found" analyses to go below the guarantee. Whatever deficiencies in analyses may be found are usually chargeable to errors in sampling materials before they are mixed or to occasional lack of uniformity in mixing. Few analyses fall below a producer's guarantee.

The enforcing agent is often the head of the State Department of Agriculture or the head of one of the departmental bureaus. He may,

and often does, assess fines on producers whose goods repeatedly or consistently fall below the guarantee. The publicity rather than the assessment of fines "controls" the analyses of fertilizers.

4. Comparing Fertilizer Materials

In addition to packing-house by-products, guano, nitrate of soda, sulphate of ammonia, and in time superphosphate and potash salts became standard fertilizer materials. Now, still further additions of plant-food carriers have been made. There are three groups: one furnishes nitrogen; the second, phosphoric acid; and the third contains potash.

Carriers of Nitrogen. In 1940 the United States had a capacity to produce nearly 600,000 tons of chemical nitrogen; about one-third of this was synthetic and the rest by-product nitrogen. In 1944 the by-product nitrogen had increased slightly, and the synthetic had more than trebled. Of this increased capacity, more than 800,000 tons was in government-owned plants. The total American capacity for the production of nitrogen was 1½ million tons in 1944. During periods of good prices for farm products, it appears probable that American farmers will use more commercial nitrogen than they did before World War II.

The carriers of nitrogen are generally referred to as *ammoniates*. A great variety of them is used in mixed fertilizers. On the basis of source, ammoniates are divided into two groups. One is composed of the materials from plant and animal sources which are called *organic* ammoniates. The second group comes from mineral sources, and these are termed *inorganic* ammoniates. The manufactured, or synthetic, ammoniates are divided between the organic and inorganic groups.

Organic Materials. Organic materials have been used longer than the inorganic ones, and of the organics, those from animal sources are the oldest. The organic materials are dilute or of low concentration.

In the dry condition, organic ammoniates have the power of absorbing water and still remaining fairly dry. For this reason organics are of special value as conditioners in home-mixed fertilizers. Organics have additional value because they contain small quantities of the important minor elements (page 281).

The important *animal* ammoniates are guano, fish meal, tankage, dried blood, and sewage sludge.

Peruvian guano has been used longer than any other fertilizer material in this country. It has been imported since 1824. Guano comes mainly from the arid islands off the coast of Peru. It consists of the remains of the bodies of sea birds, bats, and seals and their manure which has accumulated for centuries.[2]

Fish meal, or tankage, is the material left from the packing of edible fish or the material left after the oil has been removed. Some fish material is treated with acid to prevent decay and objectionable odors about the plants. The material is ground for fertilizer use.

Animal tankage consists of slaughterhouse refuse and wastes. Meat, bone, and blood are present. Its quality depends on the proportion of these different materials. Dried blood is a by-product of meat packing. Feeds and industry claim all of the good-quality blood; only a poor grade comes to the fertilizer industry.

Garbage tankage and sewage sludge are mixtures of animal and vegetable materials. Both are dilute and of low availability. Garbage tankage, in particular, is useful as drier.

Cottonseed meal, castor meal or pomace, linseed meal, cocoa cake, and tobacco stems are the important vegetable ammoniates. Like the animal materials, these too serve as driers. Cottonseed and linseed meal are largely used in dairy feeds. Some of the meal, however, finds its way into fertilizers. All the seed meals are the pulp from which the oil has been removed. Castor meal is of value only for fertilizers.

Tobacco stems are the stems and wastes from making the different tobacco products. The nicotine is often removed for use as the insecticide, Black-leaf Forty. Tobacco waste is a good drier in mixed fertilizers.

Dried muck and peat are useful as driers, but they contain only small amounts of plant food.

Inorganic Materials. There are two important inorganic ammoniates, nitrate of soda and sulphate of ammonia. In addition are nitrate of potash and nitrate of soda-potash. The latter is a mixture of sodium and potassium nitrates.

Nitrate of soda is the old standard nitrogen-carrying material that has 16 per cent of nitrogen. It has been imported since about 1830. Nitrate of soda occurs in extensive deposits of *caliche* on the

[2] See p. 285 for the nitrogen, phosphoric acid, and potash content of fertilizer materials.

west coast of South America, mainly in Chile. Nitrate of soda is dissolved out of the caliche in water and prepared for market.

Nitrate of soda is deliquescent and to avoid lumping must be stored in a dry place, away from moist wind, particularly. Nitrate gained deserved popularity because crops can use it as soon as it is dissolved in the soil moisture. It provides cool-weather crops with a supply of nitrogen before the soil is warm enough for the soil organisms to provide nitrate nitrogen. Nitrate of soda has been imported in large quantities over the years. The residual effect on the soil is distinctly alkaline. On acid soils, its continued use tends to correct the acidity, and it makes alkaline soils more distinctly alkaline. In the quantities of nitrate of soda to the acre that are generally used, no bad effects are expected.

The old-style Chilean nitrate of soda probably carried minor elements of considerable value to crops where minor elements were unavailable. Impurities are now so largely removed that little benefit from minor elements is likely, yet some slight benefit may be obtained by crops.

Sulphate of ammonia contains 20.5 per cent of nitrogen. It is obtained from coal in the manufacture of coke and of "city" gas for cooking and heating. The ammonia is passed into a solution of sulphuric acid where the two unite and form sulphate of ammonia. When the solution becomes concentrated, gray crystals of sulphate of ammonia form. These are washed and dried ready to use. Sulphate of ammonia does not absorb water so readily as the nitrates, and this is a real advantage. The nitrogen in sulphate of ammonia is in the ammonia form, some of which is used by certain plants. In moist, warm soils, organisms readily change it to nitrate. In this form plants generally can use it. The residual effect of sulphate of ammonia on the soil is distinctly acid. Used in large quantities year after year it depletes the soil of active lime and makes acid soils more strongly acid unless lime is applied. If the reaction of the soil is kept about right for the crop, there is little difference in yields from the use of the different ammoniates.

Nitrate of potash and nitrate of soda-potash are similar to nitrate of soda in many ways. The nitrogen in all three is in the same form and all are alkaline.

Synthetic or Manufactured Ammoniates. The nitrogen in these ammoniates is combined with other elements by chemical processes.

Among the more important ones are calcium cyanamide, urea, sulphate of ammonia, nitrate of soda, and ammonium nitrate (Fig. 142).

Calcium cyanamide (fertilizer grade) has 21 or 22 per cent of nitrogen. Its dark color and its value as a drier are imparted to it by carbon. If used alone, cyanamide is put on 10 days before planting time. This period is long enough for soil organisms to make the necessary changes in it. Cyanamide must not be allowed to come into contact with the seed because it reduces germination. Cyanamide is used to the extent of 50 or 60 pounds to the ton of mixed fertilizer.

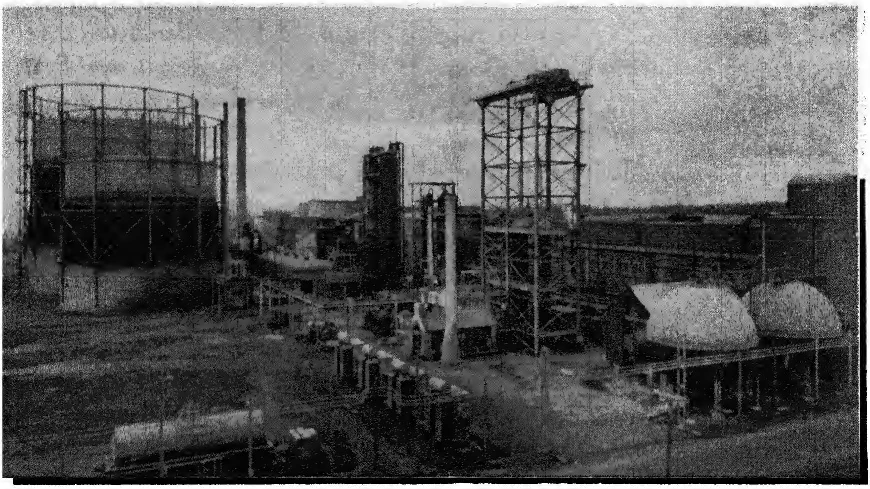


FIG. 142. Nitrogen fixation plant of the Tennessee Valley Authority. (*Tennessee Valley Authority.*)

Calcium cyanamide is strongly alkaline (see Table 28), and its calcium requires consideration in using this material. It is a relatively low-cost carrier of nitrogen.

Urea contains 46 per cent of nitrogen and is the highest in nitrogen of any ammoniate. It is white and granular and distinctly deliquescent. Its nitrogen is readily changed to available form in warm, moist soils. Urea granules are given a dark coating that reduces their deliquescence. This mixture is called *uramon,* but it is similar to urea.

Cyanamide, urea, and uramon are classified as "nonproteid organic compounds" by the official chemists. All are good sources of nitrogen. Uramon, in particular, may be used in any desired quantity to the acre.

The sulphate of ammonia and nitrate of soda are similar in every way to those already described.

Ammonium nitrate is a compound of ammonia and nitric acid; consequently it is fairly concentrated. The fertilizer product contains 32 per cent of nitrogen. It is extremely deliquescent and is treated to make it less so. Even so, it must be handled so as not to expose it to too much moist air.

Calcium nitrate, 15 per cent nitrogen, is similar to nitrate of soda.

Nitrogen Solutions. The handling of nitrogen in solutions is a recent but highly progressive movement in the fertilizer industry. Less expense is involved in handling and transporting nitrogen in solutions from the producer to the big, mixed-fertilizer factory than in any other way. These solutions are the most concentrated carriers of nitrogen. Nitrogen in the form of ammonia is the base of these solutions. In addition, such other carriers of nitrogen as urea, ammonium nitrate, and nitrate of soda are added to and dissolved in the solution of ammonia. Three of these solutions carry about 45 per cent of nitrogen, four others 37 to 40 per cent, and two additional ones 25 and 26 per cent of nitrogen respectively. The two lower concentrations have little in their favor, but the others do represent savings in freight and labor costs.

Other advantages are (1) less time required for curing of mixtures; (2) practically no conditioner required; (3) the need for acids is reduced; and (4) the mixtures do not "eat" up the bags like the old-style mixed fertilizers did. In addition, mixtures are much less acid and consequently less alkaline materials such as lime are needed to make neutral or alkaline fertilizers. This, of course, means that mixtures can be made still more concentrated than with the old materials alone.

Nitrogen solutions can be used advantageously in the larger fertilizer mixing plants rather than in the smaller ones. The dry mixer will be at some disadvantage as a consequence. An effort has been made to take the concentrated solutions to the farm, dilute them there, and apply them in the liquid form. Even if this should prove practicable, its general adoption must await the proper distributing machinery.

Carriers of Phosphorus. The term *phosphates* is frequently used for the carriers of phosphorus. In fertilizer language, phosphoric

acid (P_2O_5) is used instead of phosphorus (P). The percentage of phosphoric acid in fertilizers is 2.29 times that of phosphorus.

Carriers of phosphorus are divided into *natural*, *treated*, and *by-product* phosphates.

Natural Phosphates. Natural phosphates include bones and rock phosphate.

Bone was the earliest phosphatic fertilizer used. Bones accumu-

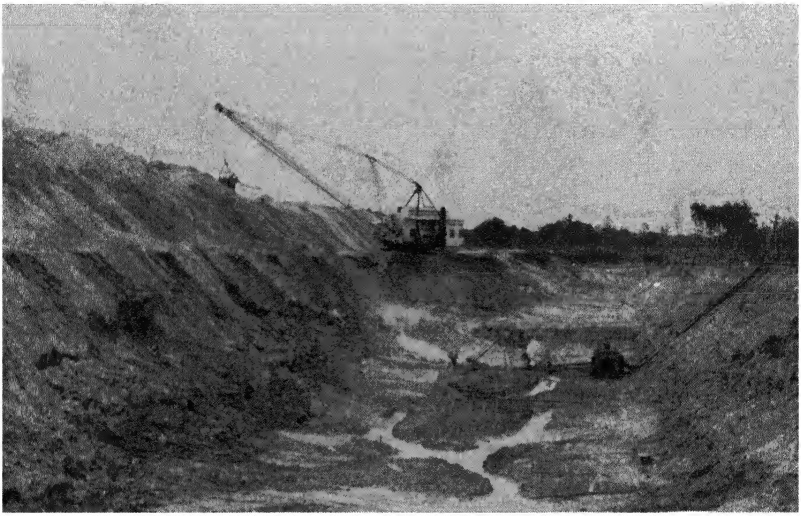


FIG. 143. Mining pebble phosphate in Florida. Pebble phosphate is obtained by strip mining. The heavy overburden of soil material, 30 feet thick in some places, is first moved to one side. Then the pebble is washed free by water under heavy pressure as may be seen in the center. The phosphate is then pumped to the washing plant. (*Swift and Company, Fertilizer Works.*)

late in packing and rendering plants. Most of them are steamed to remove fat and glue. This process makes the phosphorus in them more readily available to crops. The bones are finely ground, bagged, and sold as steamed bone meal. Raw bone meal is also used to some extent.

Rock phosphate was first found in South Carolina, and later in Florida (Figs. 143 and 144) and Tennessee. The largest domestic deposits are in Idaho, Utah, Montana, and Wyoming. These deposits are truly immense in comparison with all the eastern deposits together. For direct use on the soil, rock phosphate is finely ground. It is used untreated for feed crops in the Middle West. Although rock

phosphate is listed as "unavailable" by fertilizer chemists, crops, especially clovers and alfalfa, obtain phosphorus from it. Turned under with green material or manure on acid soils, the phosphorus slowly becomes available to crops. In areas near the Tennessee rock-phosphate field the freight rate is low and heavy applications may be used. The calcium in rock phosphate may be of value to crops, especially on acid soils.

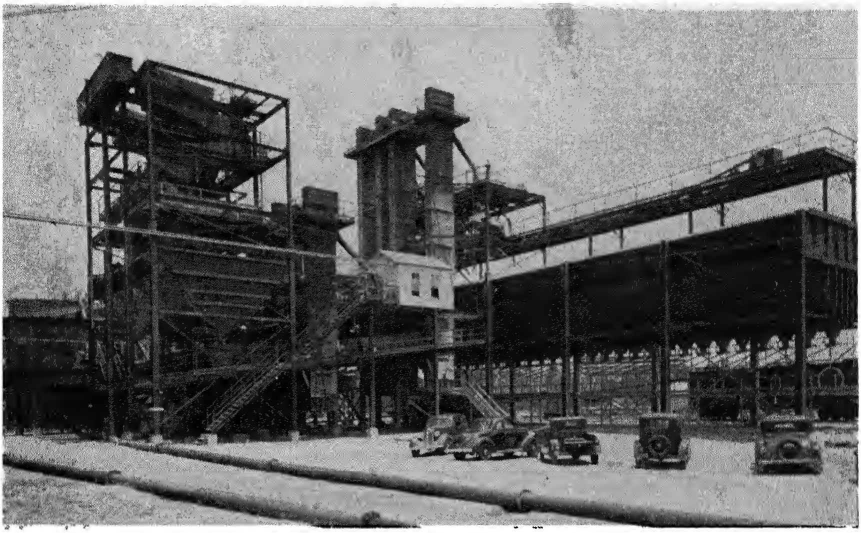


FIG. 144. Washing and loading plant. Here the pebble is washed free of non-phosphatic material and loaded into cars ready to go to the grinding and acidulating works. (*Swift and Company, Fertilizer Works.*)

Treated Phosphates. The one treated phosphate is superphosphate, which is made by mixing about 1,000 pounds of ground Florida pebble phosphate and 900 pounds of sulphuric acid. This mixture makes about 1 ton of normal superphosphate that carries about 18 per cent of available phosphoric acid. Superphosphates with 32, 40, or 45 per cent of phosphoric acid are being made at the present time. For these concentrations, rock is treated with phosphoric acid instead of sulphuric acid. Ordinary superphosphate is about one-half calcium sulphate, but none of it is present in the "double" and "treble" superphosphates because no sulphuric acid is used in making them.

Real economy attends the use of the higher analysis phosphates. It is clear that but one-half of the freight, bags, and handling are needed for the same quantity of phosphoric acid in 40 per cent superphos-

phate as in the 20 per cent product (Fig. 145). Higher manufacturing costs apparently balance this advantage at least in part. If 300 pounds of 20 per cent superphosphate to the acre are needed for a short rotation, 150 pounds of the 40 per cent grade supply the same quantity of phosphoric acid to the acre.

Ammoniated superphosphate is made by mixing superphosphate with ammonia and urea or sodium nitrate or ammonium

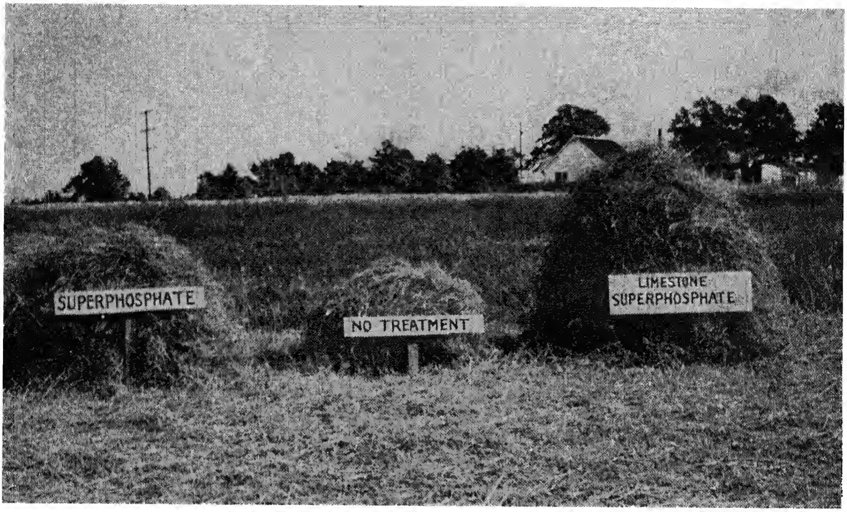


FIG. 145. Effect of phosphorus and limestone on growth of lespedeza in Oklahoma. Without treatment the yield of hay was 854 pounds an acre in 1944. Superphosphate alone increased the yield to 2,904 pounds, and lime with superphosphate further increased the yield to 3,666 pounds of lespedeza hay to the acre. Two tons of limestone an acre was applied in 1941 and 100 pounds of superphosphate an acre annually in 1942, 1943, and 1944. (*H. J. Harper, Oklahoma Agricultural Experiment Station.*) (See also Fig. 107, p. 178.)

nitrate. About 2 per cent of nitrogen is safely added to 20 per cent superphosphate.

Superphosphate, cyanamide, nitrate of soda, calcium nitrate, and mixed fertilizers are being granulated. Such fertilizer drills freely and is less subject to lumping than ordinary powdered or crystalline materials.

Calcium and potassium metaphosphates have been made on a small scale by the Tennessee Valley Authority. The calcium metaphosphate contains about 63 per cent of phosphoric acid and the

potassium metaphosphate 40 per cent of potash and 60 per cent of phosphoric acid. Metaphosphates are similar to superphosphates in the availability of phosphorus to crops. The concentration of the metaphosphates is a distinct advantage from the standpoint of costs of freight, bags, and labor.

In 1940 this country had a capacity for producing 1,700,000 tons of actual phosphoric acid or about 9 million tons a year of ordinary superphosphate. This capacity was increased about one-third by 1945.

By-product Phosphate. By-product phosphate is represented by basic slag, which is a by-product of the manufacture of iron from ores high in phosphorus. The phosphorus which is objectionable in the iron is removed in smelting. American basic slag contains only 8 or 10 per cent of phosphoric acid; European slags have up to 25 per cent.

The phosphorus in basic slag is available to crops and remains available in the soil. Slag is especially good for fertilizing acid pasture soils. Slag carries iron, calcium, magnesium, manganese, and other elements that crops need for growth. Moreover, slag corrects soil acidity. If equal quantities of phosphorus are used in basic slag and superphosphate on acid soils, slag may be expected to produce larger increases in yield. Basic slag, however, might encourage scab on potatoes in soils that were about right for best potato production.

Carriers of Potassium. Until recently much potash was imported from Germany and France. During World War II the United States not only produced the potash for its own needs, but it exported potash to Canada and to some extent to the countries to the southward (Figs. 146 and 147). During World War I, in contrast, this country, being dependent on foreign supplies, had practically no potash available. The development of domestic supplies at Searles Lake in California and near Carlsbad, New Mexico, was most fortunate. It made almost normal use of potash for crops possible throughout World War II. In 1940 the domestic capacity for the production of potash was about 500,000 tons a year in terms of K_2O. This capacity was gradually increased to 800,000 tons in 1944. This supply of potash helped American farmers to maintain a high rate of food production throughout and following the war.

Refined and Natural Potash Salts. Muriate of potash (KCl), which is refined from the crude salts, contains 60 per cent of potash (K_2O).[3]

[3] K_2O is potassium oxide, which is called potash by fertilizer men and farmers alike.

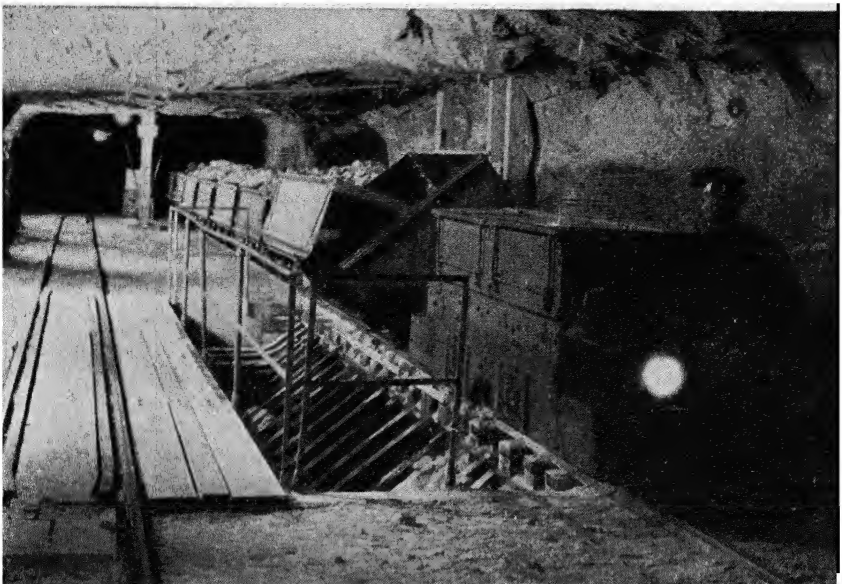


FIG. 146. Underground workings of the United States Potash Co. mine, Carlsbad, New Mexico. The cars of crude potash salts are hauled with this electric locomotive. The cars are dumped automatically and the potash hoisted to the surface in hoppers. (*American Potash Institute.*)

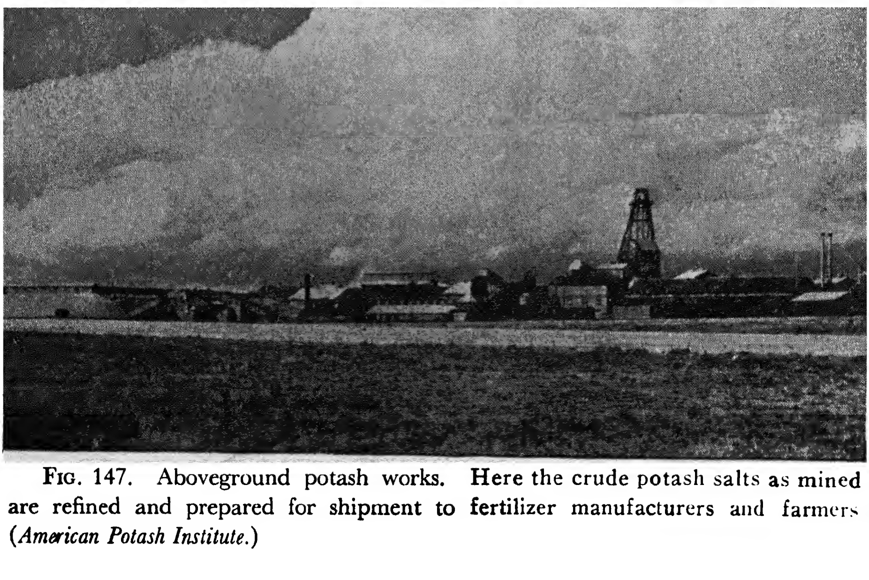


FIG. 147. Aboveground potash works. Here the crude potash salts as mined are refined and prepared for shipment to fertilizer manufacturers and farmers (*American Potash Institute.*)

This salt is soluble in water and, therefore, is available to crops as soon as it is dissolved in moist soils.

Sulphate of potash contains 48 or 50 per cent of potash and for tobacco must have less than 2.5 per cent of chlorine. It is regarded as superior to muriate for tobacco and, by some workers, for potatoes.

Sulphate of potash-magnesia has 25 per cent of potash and should not exceed 2.5 per cent of chlorine for use on tobacco.

Manure salts and kainite are the crude salts as mined, although manure salts are sometimes enriched by additions of potash. Manure salts have from 20 to 30 per cent and kainite from 14 to 20 per cent of potash. Both are used in mixed fertilizers. The long freight hauls from Carlsbad, New Mexico, to the principal agricultural regions are against their use in any considerable tonnages.

By-product Potash. There are several by-product potash carriers. Fresh hardwood ashes, which have been widely used, contain from 4 to 7 per cent of potash, up to 2 per cent of phosphoric acid, and from 20 to 35 per cent of lime (CaO). These percentages are equivalent to from 36 to 62 per cent of calcium carbonate as found in limestone. In the early days, ashes were shipped to Europe as a cash crop. Fine timber was cut and burned in order to sell the ashes for what cash they brought. Ashes today are unimportant except locally. The ash of organic wastes contains from 15 to 50 per cent of potash.

Low grades of molasses contain most of the potash that was in the juice of the sugar cane or sugar beets. When the sugar is converted to alcohol the potash remains in the residue. This residue is burned and goes to the fertilizer makers as *vegetable potash.* Its potash is in the form of potassium carbonate and is equivalent to about 33 per cent of potash (K_2O).

Miscellaneous Fertilizer Materials. In this classification are materials that carry two or three fertilizer elements. Phosphate of potash contains varying percentages of both fertilizer elements. It has from 32 to 50 per cent of phosphoric acid and from 30 to 50 per cent of potash. The higher percentage of one element goes with the lower percentage of the other. Phosphate of potash is a concentrated fertilizer although an incomplete one.

Ammophos is a compound of ammonia and phosphoric acid. Two analyses are made; one has 11 per cent of nitrogen and 48 per cent of phosphoric acid. The other contains 16 per cent of nitrogen and 20 per cent of phosphoric acid.

Sulphur is an essential plant-food element. Varying quantities of sulphur come to the soil in rain. At Ithaca, New York, 26 pounds an acre, and 45 pounds an acre at Urbana, Illinois, have been reported. Sulphur is supplied also in sulphate of ammonia, sulphate of potash, farm manure, and superphosphate. Sulphur may be used as flowers of sulphur and as gypsum. Sulphur produces intense acidity; consequently it should be used carefully.

FIG. 148. Boron deficiency of alfalfa. Some soils are deficient in boron for alfalfa and certain other crops. The growing tips turn yellow, then almost white, and finally brown and fall off on severely deficient soils. Milder deficiency may cause a blighting of the flowers and failure to set seed. Severe deficiency is associated with drought and results in reduced yields.

Minor Elements. The minor elements are boron, (Fig. 148) zinc, copper, and manganese. All plants require them for growth, but extremely small quantities are usually sufficient. Boron is supplied as borax and the other three elements as zinc sulphate, copper sulphate, and manganese sulphate.

One or another of the minor elements is deficient for various crops in different parts of the country. Some of the known instances may be noted. Boron is deficient for apples in the Champlain Valley (New York and Vermont), for cauliflower in the Catskill Mountain area of New York, for tobacco in parts of the Coastal Plain, for table beets on high-lime soils in central New York, for sugar beets and for alfalfa on occasional fields in the East.

Some Coastal Plain soils are deficient in manganese for peanuts, soybeans, and tobacco.

Some high-lime, Florida soils lack sufficient manganese for tomato production. Moreover, some of the sandy soils in Florida lack zinc and iron for citrus, and certain soils lack zinc for corn. In contrast, certain muck soils in New York contain toxic quantities of zinc.

Other Elements. Further refinement in research methods for study of fertilizer deficiencies no doubt will disclose additional soils and other crops that lack one or more of the minor elements.[4] Certain organic soils in Florida and in the northern States are deficient in copper, notably for lettuce.

Magnesium, which is not one of the major fertilizer elements, is deficient in some areas. On the basis of the magnesium content of drainage waters, many of the soils east of the Mississippi River and south of the Ohio River and east of Ohio, and of Washington and the northern two-thirds of Oregon are low or very low in magnesium. Magnesium deficiencies may, therefore, be expected in these areas. Magnesium deficiency, in fact, has been noted in regard to potatoes in Maine and to tobacco and cotton on the Coastal Plain.[5]

Although selenium is not a regular plant-food element, it is present in soluble form in certain soils in South Dakota, Montana, Nebraska, Wyoming, Kansas, New Mexico, Colorado, and other states in the Great Plains and the Rocky Mountain area. In humid regions and under irrigation, soluble selenium compounds are washed out of the soil. In the drier areas, however, soluble compounds accumulate in the soil. Under these conditions plants take up selenium to an extent that is toxic to animals eating these crops exclusively or in large quantities. They cause a disorder called *alkali disease.* Its symptoms are loss of hair and hoofs, lameness, and liver trouble. In severe cases the death rate of livestock is high. The remedy is to feed grain and forage that are free from toxic quantities of selenium.

[4] A wealth of additional information concerning deficiencies of the minor elements may be found in Willis, L. G. "Bibliography of References to the Literature on the Minor Elements and Their Relation to the Science of Plant Nutrition," 3d ed., Chilean Nitrate Educational Bureau, New York, 1939, and annual supplements since 1939.

[5] Much additional information on plant-food deficiencies of a number of crops is found in "Hunger Signs in Crops" (A Symposium), Judd and Detwiler, Washington, D.C. 1941.

5. Determining the Effects of Fertilizer Elements

On Plants. Each of the three fertilizer elements has its own more or less independent effect on the growth of crops. Fertilizers or their residues affect the reaction of the soil toward either acidity or alkalinity.

Nitrogen. Once within the plant, nitrogen acts without delay. Crops that by the yellowish or light-green color of their leaves show a lack of enough nitrogen turn dark green quickly after they are given a supply of nitrogen. Nitrogen encourages the growth of leaf and stem, the vegetative parts of plants. A plentiful supply of

Fig. 149. Effect of plant-food elements on clover. Pot 1 received no treatment; 2—lime only; 3—lime, phosphorus, and potash; 4—lime and phosphorus; and 5—lime and potash. This soil is deficient in lime, phosphorus, and potash. All three are needed for profitable yields.

nitrogen produces watery, succulent growth. This type of growth is desirable in spinach, lettuce, and celery, but most undesirable in fruits and grains. Fruits are soft and of poor shipping and keeping quality. Grains develop weak straw, lodge early, and fail to produce a good crop of seed (grain).

Unusually heavy use of nitrogen may delay ripening of fruits, grains, and vegetables that produce ripe seed. The delay may be enough to result in injury by frost. The wood of fruit trees does not

harden and suffers winter injury if too much nitrogen is used or if it is used too late. Also, too much nitrogen lessens resistance of crops to diseases. Avoid the use of more nitrogen than crops actually need.

Phosphorus. Phosphorus tends to balance the effects of too much nitrogen. Sufficient phosphorus is absolutely necessary for the complete functioning of plants. Use phosphorus to encourage blooming and setting of seed and to hasten maturity (Fig. 149). The hastening of maturity may be enough to enable a crop to escape injury from early frosts. Heavy fertilization with phosphorus might pay merely from the standpoint of avoiding damage from frost.

Phosphorus helps in the development of the tiny roots of a crop such as winter wheat. Winterkilling is less severe on well-phosphated land than on soils that lack an abundance of this element. Phosphorus enables wheat to grow well in the fall and to start early and make healthy, vigorous growth in the spring. In both fall and spring, phosphorus-treated wheat makes better growth than wheat that received nitrogen alone.

By balancing the conditions produced by too much nitrogen, phosphorus reduces the tendency of grains to lodge. Seeds, generally, are fairly high in phosphorus. Consequently, use phosphorus to increase yields of grains, plump the kernels of grains, and improve the tone, vigor, and yield of crops.

No ill effects of using heavy applications of phosphorus have been noted. Yet it is possible that excessive use on light, dry soils might hasten maturity unduly and thus reduce the yield.

Look for a shortage of phosphorus as indicated by a bronze or purplish color of the leaves of plants. Untreated Kentucky bluegrass pasture plants showed a purplish color, while phosphorus-treated grass had a perfectly normal, green color. A heavy rain carried soluble phosphorus across the narrow, untreated strips and they soon took on a normal color for Kentucky bluegrass.

Potassium. A proper balance of potassium with the other elements produces vigorous, healthy growth (Fig. 150). Under these conditions, potassium increases the resistance of crops to disease. Like nitrogen, potassium retards the maturity of crops. Moreover, potassium counteracts the effect of phosphorus in hastening ripening. Potassium is needed for the production of the green coloring matter in leaves, called *chlorophyll*, and for the development of starch.

Harmful effects of heavy applications of potassium on lettuce have

been noted. Normal, well-distributed potash, however, should produce only desirable effects on crops.

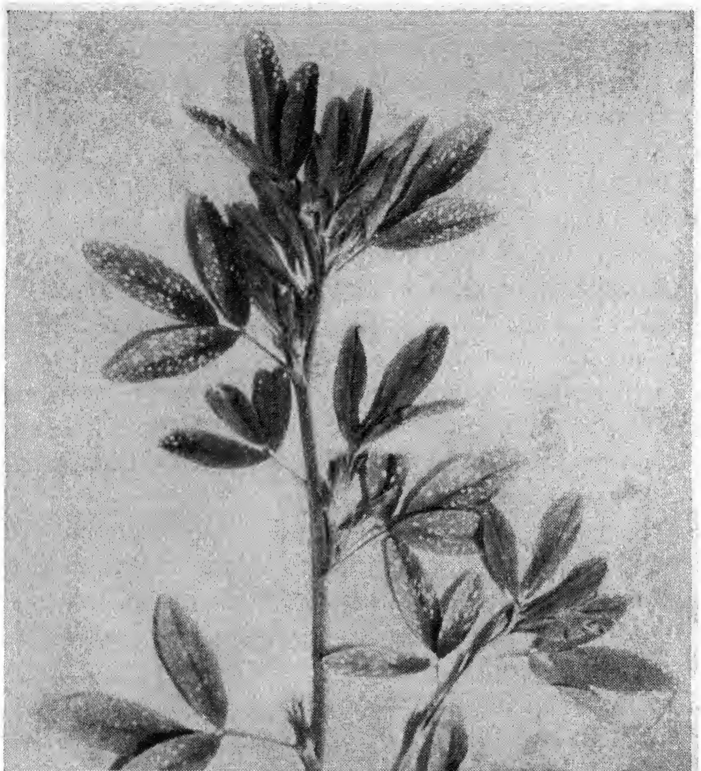


FIG. 150. Potash-deficiency symptoms of alfalfa. White spots first appear around the edges of the outer end of the leaflets until in instances of severe deficiency the leaves are fairly well covered with these characteristic white spots. Later the entire leaflets turn yellow and finally brown and die. Potash deficiency should not be confused with another difficulty whose cause is unknown. In the latter the white spots are scattered promiscuously over the leaflets, even in the early stages. (*American Potash Institute.*)

On Soils. Most fertilizer materials leave a residue that tends to make the soil either acid or alkaline. Nitrate of soda, calcium cyanamide, calcium nitrate, and basic slag leave an alkaline residue. In contrast, many carriers of nitrogen, notably sulphate of ammonia, ammonium nitrate, and urea have an acidifying effect on the soil. In time this acidifying action will cause the leaching out of so much calcium that the structure of the soil may be injured. This is more likely to occur in soils that were acid in the first place.

Table 28. Percentages of Plant Food in Fertilizer Materials and Residual Effects upon the Soil *

Material	Nitrogen	Phosphoric acid	Potash	Reaction	Residual effect upon the soil: Limestone required for neutralization of residual acidity from 1 ton, pounds	Residual effect upon the soil: Limestone equivalent of residual alkalinity from 1 ton, pounds
	Carriers of nitrogen					
Ammonium nitrate	35			Acid	1,250	
Ammophos (1)	11	48		Acid	1,097	
Ammophos (2)	16	20		Acid		
Animal tankage	5–10	3–13		Neutral		
Blood, dried . .	8–14			Acid	457	
Calcium nitrate .	15			Slightly alkaline		400
Castor meal	4.5–6.5	1.0–1.5	1–1.5	Slightly acid	120	
Cocoa cake . . .	3.5–4.5					
Cocoa shells . .	2.5			Neutral		
Cottonseed meal	6–9	2–3	1.5–2.0	Slightly acid	200	
Cyanamide (commercial)	22			Alkaline		1,260
Fish (acid)	4.0–6.5	3–6		Slightly acid	100	
Fish tankage . .	6.5–10	4–8		Slightly acid	100	
Garbage tankage	2.5–3.3			Alkaline		134
Guano	10 5	10				
Linseed meal	5	1.5				
Milorganite .	5 6	1–5				
Nitrate of soda .	16			Alkaline		583
Nitrate of potash	12–14		44–46	Alkaline		
Nitrate of soda-potash	15		15	Alkaline		
Nitrogenous tankage	6–10			Acid	320	
Peat or muck	1–3					
Sulphate of ammonia .	20.5			Acid	2,249	
Uramon	42			Acid	1,500	
Urea	46			Acid	1,660	
	Carriers of phosphorus					
Basic slag .		10–25		Alkaline		1,015‡
Bone meal (raw)	2 4	20–25†		Alkaline		
Bone meal (steamed)	1–2	23–30†		Alkaline		500
Rock phosphate		28–32‡		Alkaline		200
Superphosphate		16–45		Neutral	115	
Superphosphate, ammoniated	2	16		Acid		
Metaphosphate		63				
	Carriers of potash					
Ashes (wood)		1 5 2	4–7	Alkaline		500–1,000
Carbonate of potash			15–50	Alkaline		
Carbonate of potash-magnesia			24–27	Alkaline		
Kainite			14–20	Neutral		
Manure salts.			20–30	Neutral		
Muriate of potash			50–62	Neutral		
Nitrate of potash	12–14		44–46			
Phosphate of potash. . . .		32–53	50–30			
Sulphate of potash			48–52	Acid		
Sulphate of potash-magnesia			25–27			
Tobacco stems.	1.2–3.3		4–9	Neutral		

* Pierre, W H, Determination of Acidity and Basicity of Fertilizers, *Journal Industrial and Engineering Chemistry*, Vol 5, p. 29, 1933 † Not wholly available

‡ Cornell University, Agronomy Department, unpublished data

The quantity of pure limestone required to correct the acidity from 1 ton of each of the acidifying fertilizers has been determined. Likewise the limestone equivalent of the alkalinity of 1 ton of each of the alkaline fertilizers has been worked out. In addition to the plant-food content of the more important fertilizer materials, the limestone equivalent of the alkaline, and the limestone required to correct the acidity of the acid fertilizer materials are given in Table 28.

6. Manufacturing Commercial Fertilizers

Most mixed fertilizers are produced in giant, chemical-fertilizer plants (Figs. 151 and 152). The manufacturers are in a position

Fig. 151. Fertilizer plant in Georgia. This plant gives an idea of the size of the fertilizer-mixing job. Here the various materials are blended and mixed and then cured, bagged, and shipped out to the farmer. (*International Minerals & Chemical Corp.*)

to use a wide range of materials. They can utilize all of the least expensive materials and blend them properly. There is some value in using a large number of different materials in a mixed fertilizer. An effort can be made to produce a neutral fertilizer by balancing acid with alkaline materials. Unfortunately, the inexpensive sources of nitrogen are distinctly acid, and there are few alkaline materials that can be used in large quantities or that are not relatively expensive. The result is that most ordinary factory-mixed fertilizers made on a competitive basis are distinctly acid. Lime can be used to correct acidity in fertilizers, but lime dilutes the fertilizer or reduces its concentration.

In the larger plants, the ammonia and other nitrogen carriers in solution can be used advantageously. The ammoniation of superphosphate also aids in making more concentrated fertilizer mixtures. Combining ammonia with superphosphate improves its physical condition and, therefore, is desirable in mixed fertilizers.

In contrast to the big chemical fertilizer manufacturer is the small *dry mixer*. He buys his materials and mixes them in the dry state. Ammoniates, drier, superphosphate, and potash salts are mixed and,

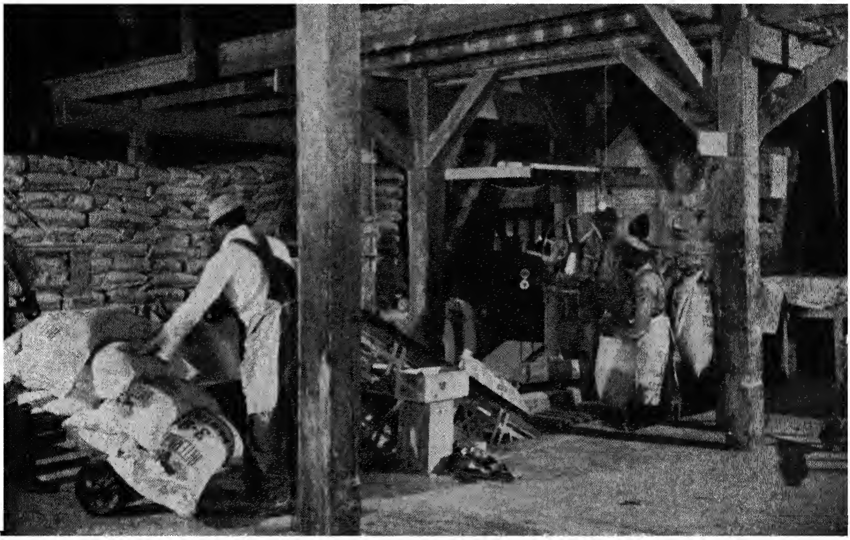


FIG. 152. Bagging mixed fertilizers. The fertilizer feeds down from overhead bins into bags on an automatic scale. From this they are moved over to be sewed up and are then automatically loaded onto the hand truck for storage or shipment. (*International Minerals & Chemical Corp.*)

if necessary, cured. If necessary the fertilizer is run through a mill, screened, and bagged ready for delivery to the farmer. The use of potassium metaphosphate, ammoniated superphosphate, and ammonium nitrate, with conditioner, might give a truly concentrated mixed fertilizer. Perfectly good fertilizer can be manufactured by either of these methods.

7. Home-mixing Fertilizers

There is less need for home mixing of fertilizers now than formerly because a wide range of fertilizers is available to the farmer and

gardener. Savings of from 10 to 20 per cent in costs are claimed but even 10 per cent in savings would justify home mixing. On vegetable farms, mixing can be done in the wintertime when the all-year labor is not otherwise profitably employed. Labor costs, therefore, are relatively low. It must not be forgotten, however, that efficiency of labor is much higher in the fertilizer factory with its machinery than on the barn floor with a shovel and screen. The use of nitrogen solutions in the factory favors factory-mixed fertilizer over that mixed at home.

If a special fertilizer, not available in the market, is needed it can be home-mixed. Tankages, the seed meals like cottonseed meal, and cyanamide or dry muck can serve as conditioner or drier in home-mixed fertilizer. The farm-mixed fertilizer is equally as effective under the crop as is the factory-mixed one. This is true even if the home-mixed one is not quite so uniform as the other.

By obtaining bids from two or more dealers on the tonnage of the mixed fertilizer you want and on the quantities of materials for home-mixing the same tonnage of the same analysis you can readily determine whether it pays to home-mix your fertilizer.

A few precautions should be observed. Do not use more than 50 or 60 pounds of calcium cyanamide in a ton of home-mixed fertilizer. It raises the temperature of a mixture and helps to dry it. Ammonium nitrate (untreated) is probably too deliquescent to be used except in very small quantities. Nitrate of soda, sulphate of ammonia, and uramon along with organic driers are good sources of nitrogen.

Following a Systematic Procedure. The suggested steps in home mixing are

1. Decide on the analyses to use.
2. Decide on the tonnage of each analysis needed.
3. Work out formulas for mixtures.

Suppose that a 10–20–10 fertilizer is needed for late potatoes. The soil will be warm and nitrate is not needed; moreover, the pH of the soil is such that there is danger of scab. Uramon is acidifying (see Table 28), relatively concentrated, and inexpensive. Ten pounds each of nitrogen and potash are needed in each 100 pounds, or 10 times 20 (hundreds in a ton) = 200 pounds each of nitrogen and potash. Twice this quantity of phosphoric acid, obviously, is required. These quantities of nitrogen, phosphoric acid, and potash are supplied by the following quantities of these materials: 200

pounds tankage, 5 per cent nitrogen = 10 pounds nitrogen in the drier. 190 pounds additional nitrogen are needed. Uramon has 42 pounds of nitrogen in 100 pounds; therefore, 190 ÷ 42 = 453 pounds of uramon needed. This gives the 200 pounds of nitrogen required. 1,000 pounds superphosphate, 40 per cent P_2O_5 = 400 pounds P_2O_5 required. 200 pounds of potash are required and muriate of potash has 60 per cent K_2O; therefore, 200 pounds divided by 60 = 333 pounds of muriate of potash needed. 200 pounds tankage + 453 of uramon + 1,000 of superphosphate + 333 of muriate of potash = 1,986 pounds in all, or practically 1 ton. No filler is needed to complete the ton.

Prepare a 5–10–10 as follows: 100 pounds nitrogen, 200 pounds phosphoric acid, and 200 pounds K_2O are needed for a ton of mixture. 200 pounds drier, 5 per cent nitrogen = 10 pounds nitrogen. 434 pounds sulphate of ammonia = 90 pounds nitrogen (90 pounds nitrogen ÷ 20.5 per cent in sulphate of ammonia = 434 pounds). 1000 pounds 20 per cent superphosphate = 200 pounds P_2O_5. 333 pounds muriate of potash = 200 pounds K_2O. 1967 pounds supplies the plant food for a ton of 5–10–10. There is no need to have exactly a ton in home mixing. Should 1,800 pounds contain all the plant food for a ton, that is entirely satisfactory. Simply use 900 pounds instead of 1,000 or 450 instead of 500 pounds of the regular ready-mixed fertilizer.

4. Get bids from two or more dealers on ready-mixed goods and on the bill of fertilizer materials needed for mixing. Pooling orders with neighbors for either mixed fertilizers or the separate materials usually obtains the lowest price. On the basis of the bids, decide whether to take ready-mixed fertilizer or the materials for mixing. Suppose it is decided to home-mix.

5. Take delivery in full carloads or truckloads.

6. Mix in off season when labor is not needed for particularly essential work.

7. Provide a smooth board, concrete, or dirt floor. Also have on hand shovels, rake, screen, and scale for weighing mixture back into bags.

8. Lay down a layer several inches thick of superphosphate, then drier, nitrogen carrier, and potash salt. Repeat with three or four such layers, using about 1 ton of the final mixture at a time. Turn the material to one side, letting the fertilizer run off the shovel and

down the side of pile. Then put it through a 3/8- or 1/2-inch screen set at an angle of 30 or 40 degrees. Lumps roll off the screen. Crush with the back of shovel and put through the screen. An additional shoveling may be desirable but is not always essential. Now refill the bags and weigh to have uniform packages. This is helpful for determining the quantity that is being applied to the acre. A dollar or two may be regarded as the cost of the labor of mixing. This varies, of course, with the efficiency of mixing and with the wages paid.

If mixing is done several weeks before using, store the fertilizer in a dry place. Stand the bags on end, preferably only one bag deep. Do not let wet wind blow over the fertilizer in storage, because the fertilizer might take up some moisture. This results in lumping of most fertilizers, and causes trouble in drilling them.

Drier is always expensive. Some farmers avoid this expense by mixing fertilizer as they use it. For this purpose they buy the carrier of nitrogen that costs least per unit of nitrogen. There is little choice of superphosphate and potash carriers. Then they mix for each day's or half day's spreading. The results on crops have been entirely satisfactory.

Determining the Advantages and Disadvantages of Home Mixing. The farmer can definitely fit his fertilizer to the soil and crop by mixing it at home. He can make it acid, neutral, or alkaline as the crop may require on any of his fields. For cabbage and cauliflower on soils that might produce clubroot, an alkaline fertilizer is made up. For potatoes on soils in which there is danger of scab, an acid fertilizer can readily be made. In fact, for some years, it has been cheaper to make an acid than an alkaline fertilizer. Likewise, a neutral mixture can be easily made. The cash saving is the principal advantage. The low cost of farm labor compared with that in the city factory distinctly favors home mixing.

The work of obtaining the materials and storing them until time to use the fertilizer are probably the main disadvantages. The higher cost of nitrogen in solid form as compared with the solutions is a disadvantage for home mixing. Home-mixed fertilizers, unless the work is carefully done, may also lack uniformity.

For home mixing, you need to know fertilizer materials, their availability to crops, which are deliquescent, which serve as driers, which cannot be mixed with others, the reaction of materials, and their

residual effect on the soil (Table 28). You also need to know the soil reaction and previous extent of manuring, liming, and fertilization. It is equally necessary to know the requirements of the crops that are to be grown. This information properly used will surely make farming or gardening more satisfying and probably more profitable.

8. Purchasing Fertilizers

Many farmers and gardeners purchase their fertilizer as they use it from the local dealer. The dealer renders them the service they demand and the user of those fertilizers pays for this service. Local dealers could give improved service if the user would place his order well in advance of the date when delivery is desired. Doing this would enable the dealer to order from the manufacturer the exact analyses (or grades) his customers want for their crops. For a group of users to pool their orders so as to accept shipment in full carlots often enables them to obtain a very low price. Purchasing fertilizer on time or credit is expensive. Such credit for a period of 6 months costs the farmer at a rate of 15 or 17 per cent annual interest. It is far better to get credit at the bank or from some other established credit agency. There is a reason for the high cost of credit on fertilizers. Under the best of conditions some accounts cannot be paid. All credit buyers, therefore, must pay a proportionate share of unpaid bills. When credit is extended on a plow or truck and payments are not made as contracted for, the dealer recovers the plow or the truck. No recovery of fertilizer is possible; it has long since been mixed with the soil. The high credit charge is not a fault of the dealer. The lesson is: Get your credit from the bank or other established lending agency and then claim the cash discounts on fertilizer.

Economizing by Buying Higher Analyses Fertilizers. The labor of mixing, bags, wear on plant, overhead, transportation, and other charges are on the tonnage basis. These costs, therefore, are approximately the same on every ton of fertilizer produced regardless of the actual plant food in it. This expense is the same on a ton of 4–8–4 as on a ton of 8–16–8 or 10–20–10. A few years ago this overhead charge was around $10 a ton including freight. On that basis, the overhead per unit in a 4–8–4 (16 units total) is 62½ cents. The cost per unit in an 8–16–8 (32 units) is 31¼ cents. In the 10–20–10 (40 units) the overhead cost is 25 cents a unit (Fig. 153). A farmer, therefore, can save 37½ cents a unit by buying the 10–20–10

rather than the 4–8–4, and both are of the same ratio. Consequently they can be used for the same crops; ½ ton of 4–8–4 to the acre supplies crops with the same quantity of plant food as 400 pounds of 10–20–10. On the equivalent of 1 ton of 10–20–10 the farmer's saving is \$15. On a 20-ton car of 10–20–10 in comparison with 2½ carloads of 4–8–4 the farmer's saving is \$300 and on 10 tons of the higher analysis, \$150.

Moreover, the ingredients in the 10–20–10 are certain to be the very best because there is no room for dilute or low-grade materials. The cost per unit of plant food in certain ingredients may be slightly

FIG. 153. A fertilizer bag. Recently paper bags have been used instead of burlap. The figures 5–10–5 represent the percentage of *total* nitrogen, *available* phosphoric acid, and *water-soluble* potash; they were on the tag sewed in at the top of the bag. These three figures indicate the plant-food value in the bag.

higher because of the cost of concentration. On the whole, however, there is every advantage to the farmer and gardener in using *concentrated* rather than *low-* or *ordinary-*analysis fertilizers.

The danger from burning the seed or the roots of crops has definitely been shown to be no greater with concentrated than with low-analysis fertilizers; therefore, do not hesitate on that score to use the higher analysis fertilizers.

9. Using Fertilizers

Fertilizer may be applied in many ways. Methods vary with the crop, the soil, and the rate of application. For grains the conventional method of putting the fertilizer down through the drill with the seed is

as good as any other that has been reported. For pastures or meadows, broadcast such materials as basic slag, superphosphate, rock phosphate, mixed fertilizer, carriers of nitrogen, or lime. For the more soluble ones, put the fertilizer on all over the soil and do not concentrate it in narrow strips under the teeth of the drill. For irrigated crops, nitrogen is sometimes applied in the water.

Localizing the Placement of Fertilizers. Much recent work has been done on the localization or special placement of fertilizer for

FIG. 154. Side placement of fertilizer for potatoes in Virginia. The fertilizer is in bands 2 inches from the seed on both sides and on a level with the bottom of the seed. (*Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture.*)

cotton, corn, tobacco, and many of the vegetable crops. Except for grains, the fertilizer should not touch the seed.

For Potatoes. The best place for fertilizer for potatoes, on the basis of experimental results, is in a band 2 inches from each side of the seed pieces on their level or a little lower (Fig 154). A little deeper placement is suggested on sloping land to avoid possible injury if the soluble fertilizer is moved downhill.

For Cotton. For cotton, place the fertilizer from 1½ to 2½ inches out from both sides of the row and 2 inches below the surface (Figs. 155 and 156). Light applications may be made nearer to the plants than heavy ones. The greater distance is better for heavy fertilization.

For Spinach. Fertilize spinach in bands from 2 to 3 inches to the sides of the rows and about 2 inches below the surface.

For Tobacco. For tobacco, fertilizer is placed by the fertilizer attachment of the plant-setting machine from 2½ to 3 inches away from the plants and about 1 inch below the crown (Fig. 157).

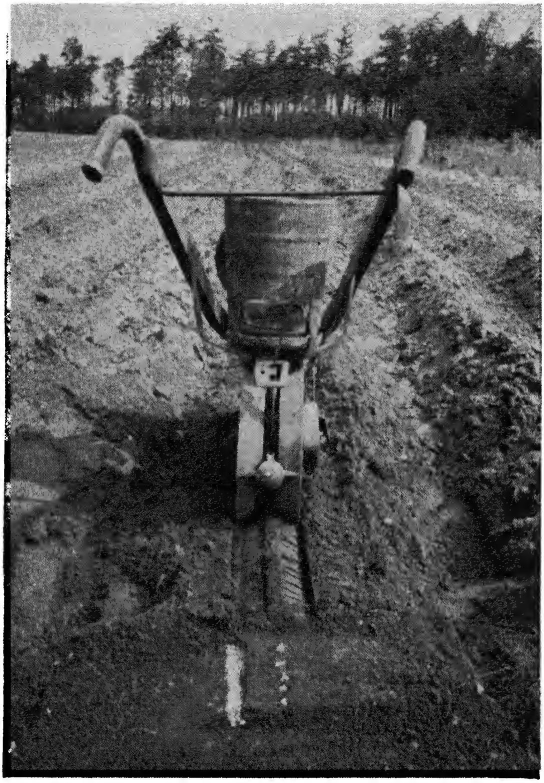


FIG. 155. Cotton fertilization. This shows the placement of fertilizer 2½ inches to one side and 2 inches below the level of the seed. (*Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture.*)

For Sugar Beets. The fertilizer for sugar beets is placed from ½ to 1 inch to the sides and from 1 to 2 inches below the surface. This recommendation is tentative.

For Corn. For drilled corn, the fertilizer is run in continuously about 1 inch from the row and from seed level to 1 inch below the seed (Fig. 158). For checked corn, the fertilizer is dropped at the hill. The fertilizer is run in bands 6 or 8 inches long about 1 inch from the

sides of the hills and about 1 inch below the seed level. Because the fertilizer is spread continuously, heavy rates can be used more safely than if the fertilizer is all placed in the short bands opposite the hills.

FIG. 156. Fertilizer on both sides of the cotton seed in Georgia. (*Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture.*)

FIG. 157. Effect of fertilizing tobacco. The plants on the left have been adequately fertilized; those on the right have not. (*Bureau of Plant Industry, Soils, and Agricultural Engineering, U.S. Department of Agriculture.*)

For Beans. For beans, both field and snap, place fertilizer on both sides of the row, $1\frac{1}{2}$ to 2 inches away and from 1 to 2 inches below the level of the seed. A little variation is suggested between snap and

dry beans, but these variations are within the distances mentioned here.

For Sweet Potatoes. Place the fertilizer for sweet potatoes 4½ inches from the sides of the rows of plants and about 3 inches below the surface if 1,000 pounds of fertilizer are used.

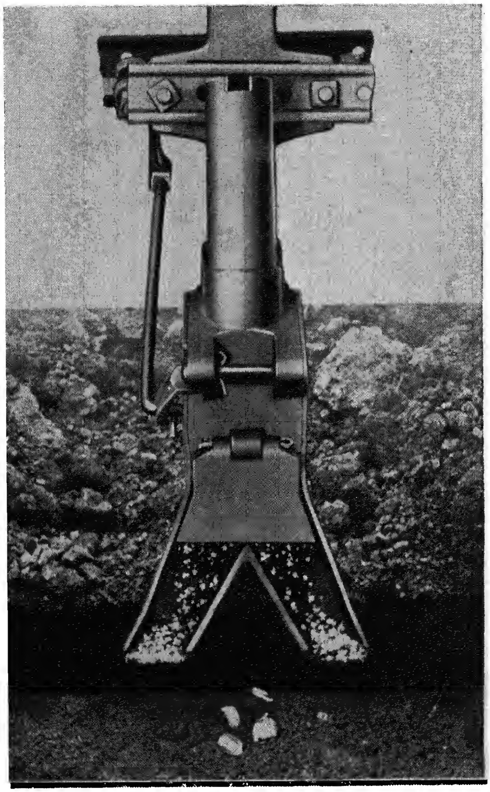


FIG. 158 Side application of fertilizer for corn. This shows how the fertilizer is placed with respect to the seed. (*International Harvester Co.*)

For Cabbage. For cabbage, fertilizer is placed about 2½ inches from both sides of the row and 3 or 4 inches below the surface. The fertilizer is applied by the transplanting machine at the rate of 600 pounds of 4–16–4 to the acre.

For Cannery Peas. Fertilizer placed 2 or 2½ inches away and to the side of the seed and 1 inch below the level of the seed produced good results in the East. On heavy soils in Wisconsin, 200 pounds of fertilizer was put on in the row with the seed with no ill effects.

Probably some refinement in these distances both to the side and in depth below the surface will be made as localized fertilizer-application studies are continued. Also, it may be found that there is a fairly definite zone both horizontally and down into the soil within which fertilizer may be placed with good results. Some variation in the proper placing in wet and droughty periods is likely to be found.

Determining Rates of Fertilization. The amount of fertilizer to use for a crop varies with several conditions. Among these condi-

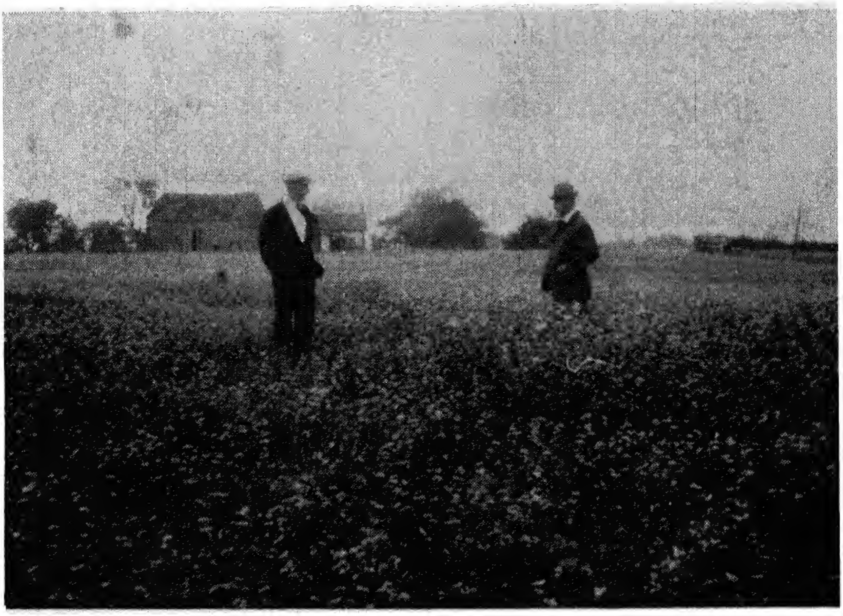


FIG. 159. Effect of superphosphate on buckwheat in Vermont. At right, 500 pounds of superphosphate was used to the acre; at left, none. A much higher yield may be expected on the phosphated plot. (*E. Van Alstine.*)

tions are (1) value of the crop and prospects for profit; (2) the response of the crop to fertilizer; (3) the kind of soil; (4) the cost of fertilizers; and (5) the climate.

Value of Crop and Profit Prospects. Crops vary widely in the returns they produce to the acre. Buckwheat (Fig. 159) usually makes a low total return to the acre. Selected fruits and vegetables, in contrast, yield comparatively large returns to the acre. Clearly, high-return crops may be fertilized more freely than low-return ones. Another point to have in mind before making heavy applications of fertilizer

is the price situation. If the prospects are for a satisfactory price level for produce, either stationary or rising, plan for liberal fertilization. If a drop in prices appears certain before crops can be placed on the market, use caution in making heavy outlays for fertilizer.

Response of Crops. Crops are not all alike in their ability to take nourishment from soils. Leguminous crops and grains usually respond to phosphatic fertilization. Most vegetable crops require all three of the fertilizer elements for the production of good yields. Liberal fertilization is essential, too, because the root systems of these crops are usually somewhat less extensive than that of some of the feed crops.

Kind of Soil. Heavy soils are more retentive of water and fertilizer than light ones. The light soils provide little plant food for crops and, therefore, need more applied plant food than heavier soils. Previous liming, fertilizing, and manuring are usually of greater residual effect on the heavier soils. On the other hand, there is more risk in fertilizing light, droughty, nonretentive soils than the heavier ones. If heavy fertilization is practiced, it may be well to split the application. Thus, there is less danger of heavy loss by leaching. Here is a situation that merits consideration of the benefits of irrigation.

Cost of Fertilizers. A low cost of plant food in comparison with the prices of crops encourages liberal use of fertilizer. Low cost of high-grade plant foods greatly increases the chances for profit from the use of fertilizer. Consult page 291 for some suggestions on obtaining more for the fertilizer dollar.

Climate. The climate, particularly the rainfall during August in the North, requires consideration in determining the rate at which to apply fertilizer. In humid regions with ample, well-distributed rainfall, fertilizers may be used liberally. Even there, however, the fertilizer remains in the soil largely unused at the end of dry seasons. In the transition from the humid to the dry-farming area, moderate fertilization, if any, is advised. There are two reasons for caution: (1) A moderately liberal supply of nitrogen, especially early in the season, encourages vegetative growth of the plant. When dry weather arrives, the root system is unable to supply the plant with the water it needs. Wilting and finally death may follow. (2) The fertilizer may increase the salt content of the soil so as to be harmful to the crop in dry periods. For dry areas, therefore, use fertilizer moderately if at all.

Using Borax with Care. Some fertilizer manufacturers have recently added a small quantity of borax to mixed fertilizers. The quantity is so small that it can do no harm if the fertilizer is mixed uniformly with the soil. When even 200 pounds to the acre is applied in the drill row with oats, the concentration around the seed is far greater than 200 pounds to the acre uniformly distributed over the

FIG. 160. Fertilizing a farm fish pond. A shallow pond can be thus fertilized by hand from the shore. Boats are used to fertilize large ponds. One hundred pounds or more of complete fertilizer to the acre is used several times during the season. (*H. S. Swingle, Alabama Agricultural Experimental Station.*)

area. The concentration is sufficient to reduce germination of the grain and also the yield. It is, of course, an open question whether borax should be added to fertilizer for general use if boron is not known to be needed in the entire area in which the fertilizer is sold. When borax is added, follow the manufacturer's suggestions for applying the fertilizer. It must be thoroughly mixed with the soil if damage is to be avoided.

10. Fertilizing Farm Fish Ponds

Partly, at least, as a result of work in Alabama, Missouri, and by the Soil Conservation Service, deep interest is developing in farm

ponds for multiple uses. These ponds may supply water for livestock, spraying fruits and vegetables, irrigating vegetables and other food crops, and possibly may be used for skating, swimming, and boating, but fish are included in all of them. Most of the fish pond can be shallow—3 or 4 feet in depth as a feeding ground—but there must be

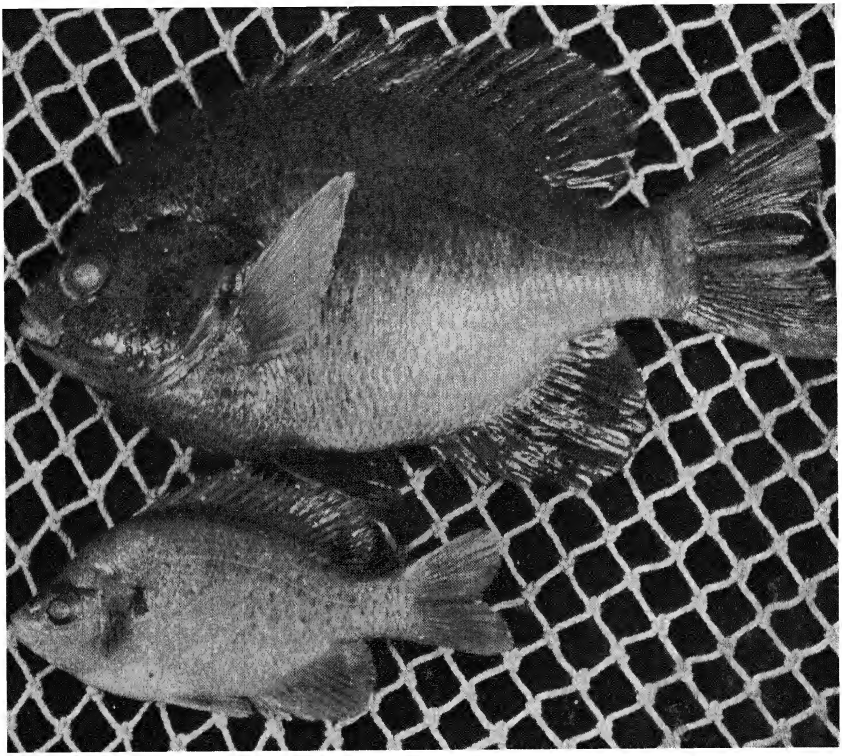


FIG. 161. Effect of fertilization of ponds on the growth of fish. Two ponds were stocked with 1,500 blue gills per acre. The upper fish grew in a fertilized pond and weighed 4.0 ounces; the lower fish in the unfertilized pond at the same age weighed 1.1 ounces. By fertilizing, nearly four times as much fish was produced as without fertilization. (*H. S. Swingle.*)

an area that is 6 or 8 feet deep to provide cool water for the fish. As much as 400 or 600 pounds of fish an acre is produced in Alabama, but 100 or 200 pounds is believed a more likely yield in the shorter growing season of the North.

Fish feed largely on the tiny green algae that grow in the water. Like higher plants, algae require plant food—nitrogen, phosphoric acid, and potash. Fish, like other animals, grow rapidly if they have

a plentiful supply of feed and slowly if starved. It has been found feasible to fertilize fish ponds if they do not have too much water passing through them (Figs. 160 and 161), as this dilutes the fertilizer and carries much of it away so that the algae get little benefit from it. A good condition is one in which the algae give the water a greenish tinge and it is slightly opaque with algae. In small ponds scatter the fertilizer in the water from the banks; the waves distribute it sufficiently. In larger ponds, it is better to fertilize the water from a boat.

In Alabama they use 100 pounds of 6–8–4 an acre a week in the spring and once in 4 to 8 weeks in summer. New ponds are given

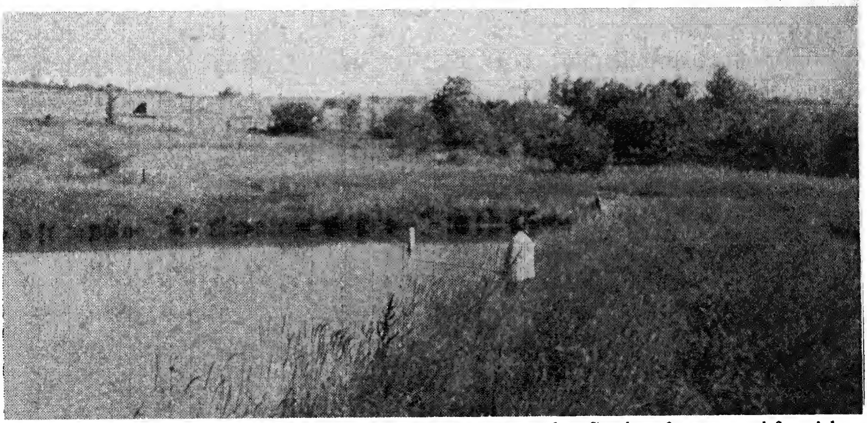


FIG. 162. Fishing from the shore of a small farm pond. Such a farm pond furnishes not only delightful recreation but considerable quantities of food.

two or three applications before they are stocked. In the North similar fertilization with 8–8–4 is recommended. The bluegill bream lives largely on a vegetable diet of algae. To prevent the bream from becoming so numerous as to outrun its feed supply, large-mouth bass, a carnivorous species, is placed with the bluegill bream. If the pond is well fertilized so as to produce an abundance of feed for the bream, the bass multiplies according to its feed supply—the smaller bluegills. Thus, the numbers of both are fitted to the supply of feed. By producing an abundance of algae, fertilization enables the fish to make rapid growth under favorable conditions (Fig. 162).

SUMMARY

1. In the early days refuse and waste products, mainly, from slaughter-houses and rendering plants were used as fertilizers. Today, fertilizers are produced by a giant chemical industry.

2. The American fertilizer industry had its beginning about the middle of the 19th century. At that time it produced only a few thousand tons each year, yet in both 1944 and 1945 more than 12 million tons of fertilizer were produced and used on American farms.

3. To know fertilizers, you will need to understand ordinary fertilizer terms.

4. The states "control" the composition of fertilizers by means of collecting samples, analyzing them, and publishing the analyses. The claimed analysis and the weight of the contents are shown on each bag of fertilizer.

5. Fertilizers consist of four groups of materials: (*a*) carriers of nitrogen, (*b*) carriers of phosphorus, (*c*) carriers of potassium, and (*d*) the minor elements.

6. The nitrogenous materials cover a wide range in regard to concentration, effect on soils and crops, cost per unit of nitrogen, and methods of manufacture.

7. Superphosphate, which is made mainly from ground Florida pebble phosphate, is the leading phosphatic fertilizer in use in the United States. Some finely ground, raw, untreated rock phosphate, however, is used directly on soils in the Middle West.

8. Potash comes from old saline lakes in California, from underground deposits in New Mexico, and from residues from the manufacture of alcohol from molasses.

9. Each of the fertilizer elements—nitrogen, phosphoric acid, and potash—has fairly specific effects on crops. Nitrogen has the quickest, most pronounced effects. It encourages the growth of stem and leaf and delays maturity. In large quantities it weakens stems and causes lodging of grains and softness in fruits, but it gives tender crispness to such vegetables as spinach, lettuce, and celery.

10. Phosphorus hastens maturity and in general balances the effects of nitrogen. Potash balances the effects of the other elements and gives tone and vigor to the plant, but it tends to delay maturity.

11. Certain carriers of nitrogen tend to make soils acid; others tend to make them alkaline. The other elements have little effect on the reaction of the soil.

12. The mixed fertilizers on the market are made in large commercial factories, principally by chemical processes. Entirely satisfactory fertilizers, however, can be made by home mixing on the farm. Home mixing has some advantages and some disadvantages. A particular advantage is providing special needed mixtures that are not regularly on the market.

13. High-analysis fertilizers are more economical than, and just as safe to use as, the lower-analysis ones.

14. Liberal fertilization is desirable for crops that respond well to

treatment, particularly during times of high crop prices. Low-return crops, however, will pay for only light applications.

15. Localizing the placement of fertilizer in bands on one or both sides of seeds or plants and 1 or 2 inches below the level of the seed is favored. Plowing under part or all of the fertilizer is a recent development.

16. The rate of use of fertilizer depends on several factors; the most important is the prospect for profit resulting from its use.

17. Borax is lacking in sufficient quantities in certain soils. Because so little of it is needed, some crops are injured by borax. Use it with care.

18. Small, specially made fish ponds on farms are a recent development. Fertilizing them increases the growth of plants in the water and, in turn, the quantity of fish produced.

12. Planning Systems of Crop Rotation

THE production of crops in a regular order over a period of years is called *crop rotation*. The idea of crop rotation is not an American development. The famous four-course Norfolk rotation of (1) turnips, (2) barley, (3) clover or beans, and (4) wheat was developed in England many years ago. Farmers in this country have practiced more or less regular rotations for many years. The need for rotating crops has increased because of the depletion of the soil by cropping and washing. Potatoes are being heavily fertilized and grown on the same land year in and year out. How long the growing of potatoes in this way can go on without severe reduction in yields, we do not know yet. Grasses, and grasses in mixture with legumes, are grown satisfactorily for hay or pasture over considerable periods. Legumes and grasses do "run out" in time and require reseeding. Practicing a regular rotation of crops has real economic advantages. The problems and the advantages of rotating crops are discussed under the following headings:

1. Determining Benefits from Rotating Crops
2. Developing Rotation Systems
3. Choosing Suitable Rotations

1. Determining Benefits from Rotating Crops

There are real benefits to be derived from following a regular rotation of crops as closely as possible. Occasionally a crop fails and a substitution must be made. The alternative crop, however, should be one that permits getting back into the regular rotation as easily and quickly as possible. Some rotations are better than others. Good rotations of feed crops contain one year or more of leguminous hay crops. Some of the leading advantages of regularly rotating crops are discussed in the following paragraphs.

Increasing Crop Yields. Corn, oats, and wheat in rotation with clover and timothy produce larger yields than they do when grown

continuously. Experimental work that has been done over the country for long periods shows clearly this improvement in yields. Typical results from rotation experiments have been selected and are cited here. Thorne worked with corn, oats, wheat, clover, and timothy in a 5-year rotation in Ohio. Some of his data is given in Table 29.

TABLE 29 EFFECT OF ROTATION AND CONTINUOUS CROPPING OF CORN, OATS, AND WHEAT IN OHIO* (1914-1923)†

Crop	Treatment	Yield, bushels		Increase	
		Continuous	Rotation ‡	Bushels	Per cent
Corn.	None	15.9	19.0	3.1	19.5
	N-P-K	33.3	45.6	12.3	36.9
	Manure	17.8	37.5	19.7	110.7
Oats.	None	17.6	29.7	12.1	68.7
	N-P-K	37.0	56.3	19.3	52.2
	Manure	25.4	42.7	17.3	68.1
Wheat	None	6.8	11.4	4.6	67.6
	N-P-K	19.3	25.2	5.9	30.6
	Manure	15.5	14.9		−3.0

* THORNE, C. E., The Maintenance of Soil Fertility, *Ohio Agricultural Experiment Station Bulletin* 381, pp. 300-315, 1924.

† These data are for the third decade of the 30 years reported in this publication.

‡ Rotation: corn, oats, wheat, clover, timothy. Treatment was identical on these crops, continuous and rotated.

Corn was not greatly benefited by rotation without either manuring or fertilization, yet the rotated corn produced nearly one-fifth more grain than the continuous corn. The rotated oats and wheat yielded two-thirds more grain than did the continuous oats and wheat. Untreated, however, these yields could not be profitable. Rotated corn that received fertilization with nitrogen, phosphorus, and potash produced one-third more grain than did the continuous corn. Oats and wheat with fertilizer gave increases for rotation of one-half and nearly one-third respectively. Rotating corn that was manured produced the most pronounced effect. The yield of the manured rotated corn was more than double that of the manured continuous corn. The residual effect of the manure on the rotated oats compared to manured continuous oats was an increase of more than two-thirds in yield. Rotated wheat with manure dropped below the manured continuous wheat by 3 per cent. Although this apparent loss is

within experimental error, a loss might be expected. Bear in mind that these results are from the third 10-year period of the experiment or that these yields are an average for the 21st to the 30th years. Increased yields of corn and oats from manuring over the years on the rotated plots had reduced the supply of available phosphorus, potash, and minor elements considerably in that period of years. This loss of itself would explain a loss in yield. Also, wheat is two years removed from manuring so that less effect might be expected than on corn and oats.

The oldest experimental plots in this country are those of the Illinois Agricultural Experiment Station at Urbana. Continuous corn has been compared with corn and oats, and with a 3-year rotation of corn, oats, and clover. This experiment has been carried on since 1879, or two-thirds of a century. The yields given in Table 30 are averages for the years 1925, 1931, and 1937, when all the plots were in corn.

TABLE 30. EFFECT OF ROTATIONS AND CONTINUOUS CROPPING ON YIELD OF CORN IN ILLINOIS*

Cropping condition	Treatment	Yield, bushels	Increase in yield due to rotation, bushels	Increase over continuous corn, per cent
Continuous corn	Untreated	23.3		
	Treated†	41.6		
Corn and oats . . .	Untreated	31.7	8.4	36.5
	Treated†	58.5	16.9	40.6
Corn, oats, and clover . .	Untreated	42.5	19.2	82.4
	Treated†	62.8	21.2	50.9

* BAUER, F. C., of the Illinois Agricultural Experiment Station, unpublished data in a personal communication, 1938.

† The "treated" half of each original plot has been treated with manure, limestone, and rock phosphate since 1904.

Corn and oats in rotation produced a yield of one-third more grain than did continuous corn with no fertilization whatever during all that period. Corn in the rotation of corn, oats, and clover untreated, produced nearly twice as much grain as did untreated, continuous corn. Since 1904, one-half of each original plot has been given manure, limestone, and rock phosphate. This treatment increased the effect of the corn-oats rotation, but decreased the effect of the corn, oats, clover rotation.

These experiments have been discussed in some detail because of the long period over which they have been carried on. Data from both experiments show that rotation under these conditions increased the yield of corn. And beyond question the yields from the whole rotation were worth more than the low yields of the continuous corn.

Additional information on the financial benefits of cropping in rotation are available from the Missouri[1] and Iowa[2] Agricultural Experiment Stations. The data are given in Table 31.

TABLE 31. AVERAGE ANNUAL ACRE VALUE OF CROPS GROWN IN ROTATIONS OF DIFFERENT LENGTHS IN MISSOURI AND IOWA

Years in rotation*	6	4	3	2	Continuous corn
Missouri	$14 48	$17 82	$14 18	$16 07	
Iowa-10-year period. . .	27 86†	33 93	24 62	22 70	$24 05

* Missouri 6-year rotation—corn, oats, wheat, clover, timothy, timothy, 4-year rotation—corn, oats, wheat, clover, 3-year rotation corn, wheat, clover, 2-year rotation—wheat, clover

† Five-year rotation

The Missouri and Iowa crop values were calculated on different prices. Both series of values are consistent within themselves. The outstanding point, perhaps, is that the 4-year rotation produced the best average annual return at both of these experiment stations even though corn occupied a higher percentage of the acreage. The 2-year rotation in Missouri is not strictly comparable with the longer ones because no corn was grown in this rotation. One-half of the land was in wheat each year—a favorable cash-crop situation.

In Ohio[3] a 4-year rotation of (1) corn, (2) potatoes, (3) wheat, (4) clover was changed to (1) potatoes, (2) corn, (3) wheat, and (4) clover. The second arrangement produced crops worth $7 more an acre than if corn preceded potatoes. This increase is the result of placing the best cash crop in the most favorable place in the rotation as has already been suggested. The potato yields were 103 bushels in

[1] MILLER, M. F., and R R. HUDELSON, Thirty Years of Field Experiments with Crop Rotation, Manure, and Fertilizers, *Missouri Agricultural Experiment Station Bulletin* 182, 1921.

[2] STEVENSON, W. H., P. E. BROWN, and L. W. FOREMAN, Crop Returns under Various Rotations in the Wisconsin Drift Area, *Iowa Agricultural Experiment Station Bulletin* 241, p. 255, 1926.

[3] Forty-third Annual Report, *Ohio Agricultural Experiment Station Bulletin* 382, p. 21, 1924.

the first, and 146 bushels an acre in the second rotation. Really profitable yields of potatoes would have widened the margin in favor of placing potatoes ahead of corn in this rotation.

Producing Similar Acreages of Crops Each Year. To have one, two, or three times as many fields or areas as there are years in the rotation is desirable. And it helps to have fields of approximately the same size for each crop. Where the fields vary considerably in size, some adjustment may be necessary to obtain approximately the same acreage of each crop every year. This can be accomplished, in part at least, by growing a given crop on one large field and one small one in a series of fields that provides two for each crop. On strip-cropped land it is not so difficult to maintain fairly uniform acreages. Similar acreages of every crop each year are desirable for several reasons; among them are

1. About the same number of dairy cows or other livestock is kept on the farm from year to year. Feed requirements are approximately the same each year and this alone calls for similar acreages of leguminous and grass crops for hay. Moreover, about the same acreage of crops is needed to fill the silo each year. Similarly, the need for grain and bedding varies little from year to year and the same acreage is needed to produce it on the basis of average yields.

Many farmers carry over hay and grain from the years of higher-than-average yields to help out in the years of lower-than-average yields. Planning a definite carry-over of 5 or 10 per cent of a year's needs of grain and hay in livestock farming is desirable in areas where yields are rather uniform from year to year. Wherever there are large variations in yield because of droughty periods, because of droughty soils, or for other reasons, a larger carry-over is advisable. This arrangement requires some excess storage capacity for both hay and grain.

2. Because the family needs for cash are similar from year to year, similar acreages of cash crops each year are highly desirable.

3. Uniform acreages of plowing, seedbed preparation, cultivation, and harvesting make possible a better use of the farm labor. This uniformity is possible only with a rotation of crops that is closely adhered to.

The question is often raised as to how to continue a regular rotation if a meadow seeding fails. In a rotation such as corn the first year, small grain the second, clover the third, and timothy the fourth,

losing the seeding of clover and timothy breaks up the rotation. An easy solution is to sow oats with clover in it where clover failed. Oats then occupies the third year of the rotation. Cut the oats for hay. They are a good substitute for clover, although lower in protein. You will then have clover the fourth year instead of timothy, but that is usually entirely satisfactory on the dairy farm. Millet and Sudan grass might take the places of clover and timothy, but this requires two extra plowings in 4 years instead of one for growing oats in place of the failed clover.

Improving Control of Weeds. There is something of an association of certain crops with certain weeds. Some weeds are confined almost exclusively to cultivated land and others to meadow or pasture lands. A few weeds grow in most crops. Perennial morning-glory or black bindweed thrives in the productive soil of Middle Western corn fields. In thrifty meadows of clover or alfalfa the competition is pretty keen with the wild morning-glory, and these hay crops supply a measure of control. In the East, in contrast, it is the long-term meadow weeds that require control. Such weeds as orange hawkweed (devil's-paintbrush) thrive in old meadows. And as the meadow becomes thinner the hawkweed grows more luxuriantly because it has so little competition from the hay-crop plants. Plowing for a cultivated crop brings this type of old meadow weed under control. Most sections have weeds that occupy similar positions with respect to crops.

Although *all-grass* farming has distinct advantages from an erosion-control standpoint, the need for plowing to control the old-meadow type of weeds raises important questions concerning this practice.

Regular rotations with clean-tilled crops at definite intervals to break up meadow weeds, and thick stands of thrifty grains, legumes, and grasses that smother annual weeds, help greatly in the whole problem of weed control.

Improving the Control of Insects and Plant Diseases. Rotating crops can help in the control of insects and plant diseases. A few examples follow. Where the European corn borer is well established, growing corn year after year is practically certain to increase greatly the number of borers. Rotating corn, therefore, with clover or crops that do not serve as a breeding place for the borer should help to hold down the number of borers.

Growing cabbage or other cole crop frequently on soil that has a

degree of acidity that is favorable for the development of clubroot may lead to severe infection with this clubroot organism. An extremely heavy application of hydrated lime is expensive, but it controls this organism. Otherwise, cole crops must be kept off the land for a period of years. Doing this makes a long rotation if cole crops are to be grown regularly. These illustrations indicate how rotation of crops helps to control weeds and plant diseases.

Potatoes are a little different. They can be grown without rotation, at least for a considerable time. The wireworm does not infest soil that grows potatoes year after year. It thrives in grains and grasses but not in legumes. A short rotation of legumes and potatoes is feasible except that much of the year following potatoes is required for establishing the legume. On sloping lands in particular, compromise between control of wireworm and control of erosion may be necessary. Some use of grasses may be required to conserve the soil, and this may be followed by some loss from injury by the wireworm. Potato-scab injury must not be overlooked in liming for the production of legumes.

Improving the Distribution of Feeding Roots. Some crops have deeper root systems than others. During one year, crops draw much of their nutriment from one particular zone. Next year, in rotation, the crop roots deeper and obtains its nourishment from a greater depth. If one crop is continued many years, its root zone tends to become exhausted and lower yields are the result. Rotating deep- with shallow-rooting crops increases the yield of crops.

Helping to Maintain Organic Matter in Soils. Clean-cultivated crops deplete the soil of organic matter rather rapidly, particularly if they are grown every year over a considerable period. Small grains such as wheat, oats, and barley use up organic matter about one-half as rapidly as do clean-cultivated crops. The biennial legumes such as sweet and red clover (although some plants live longer) and perennials, such as alfalfa and the white clover, add organic matter and nitrogen in the first hay year to about the same extent that a crop like corn uses up organic matter. The crop during the year of hay following red clover appears to add about one-half as much organic matter and nitrogen as a small-grain crop uses. The grass the fifth year, after the mixed hay the fourth year, neither adds nor takes away organic matter and nitrogen. A 5-year rotation of corn, oats, clover, clover-timothy, and timothy, according to this

simplified and generalized calculation, loses a little organic matter. (Corn, -2 + oats, $-1 = -3$. Clover, $+2$ + clover-timothy, $+\frac{1}{2}$ + timothy, $+ 0 = +2\frac{1}{2}$. If the nitrogen from rains, and a little fixed by organisms in the soil, is used by crops and converted into organic matter, this rotation should break even on organic matter. In contrast, continuous corn would deplete the supply to the extent of 10 per cent of the organic matter in the soil at the beginning of the 5-year period of this rotation.)

From this it is clear that, as compared with growing a depleting crop continuously, a rotation does much to maintain the organic content of soils. The possibility of the additional benefits of growing alfalfa, or other long-lived legumes, in the clover and clover-timothy (third and fourth) years of this rotation requires consideration. It needs to be understood, however, that alfalfa does not go on piling up organic matter and nitrogen in the soil at the rate assigned to "clover" over a long period of years. No doubt it does as much or more than clover for the soil for a year or two or somewhat longer. Alfalfa may be expected to do better by the soil than the clover-timothy feed-crop combination. Beyond question, lespedezas function very satisfactorily in the agricultural areas to which they are well adapted.

The possibility of growing a leguminous catch crop in grains that are not seeded to a meadow mixture (Chap. 13) should not be overlooked, nor should that of growing leguminous winter-cover or green-manure crops in the areas with long growing seasons.

Improving the Tilth of Soils. Medium- to heavy-textured soils on which clean-tilled crops are grown for several years in succession, or such crops alternated with the small grains, develop poor tilth. In this condition, the granules are more or less broken down, water percolates into the soil slowly because the soil is compact, and aeration is slow. These conditions are unfavorable for good crop growth.

The roots of hay and pasture grasses, together with legumes, tend definitely to bring about granulation. A good thrifty grass sod, when turned over in plowing, is usually in good physical condition for the production of clean-tilled crops. It should be borne in mind, however, that meadows or pastures produce this desirable condition in the period usually devoted to them in an ordinary rotation of 4 years or more. Long periods in hay or pasture mixtures do not continue

to improve this condition much beyond what is accomplished in 2 or 3 years.

In general, therefore, it is seldom that crops, especially clean-cultivated ones, should be grown continuously over any long period. It is true, however, that under certain conditions, such as with gardens and intensive vegetable production, rotation is not practiced. The return of organic matter as animal and green manures, however, is desirable, if not absolutely necessary, on medium- and heavy-textured soils that are cropped continuously.

Helping in the Control of Erosion. The protection that grasses, legumes, and small grains afford the soil against erosion by wind and water during their growth should not be overlooked. Moreover, the roots of the grasses hold the soil during the year in which the clean-cultivated, or soil-exposing crop is grown.

2. Developing Rotation Systems

All of the beneficial effects of rotating crops need full consideration in the development of a desirable and appropriate rotation. Of course, the sequence of crops in many rotations is fixed by the needs of crops or the way they dovetail with one another and the saving of such work as plowing. Any cash crop, such as tobacco, corn, cotton, peanuts, potatoes, beans, or cabbage, to mention only a few of the clean-tilled ones, deserves the best place on the rotation (Fig. 163). This crop should have the full benefit of manuring and the plowing down of grass or mixed-legume sods. The extent to which a crop protects the soil or exposes it to erosion by wind or water also requires consideration. In livestock farming, the requirements for roughage and grain feeds must have a share of attention. The practice has developed of mentioning first the clean-cultivated or important grain crop, and this will be continued here.

Purely for purposes of brevity and clarity the names of crops will be used. The clean-cultivated year is represented by corn. Any other clean-tilled crop, of course, may be grown in the same place in the rotation. Likewise, oats, for short, represents any small-grain crop, clover the first year of hay crops, and timothy the second hay year. Lespedezas in their area of adaptation, alfalfa, or other green-manure or hay-crop legumes may be grown in what is called the "clover" year. With this as a basis we may proceed.

Corn is essential as the grain crop for fattening hogs or cattle. Sod is plowed and manure applied for it. Corn, therefore, constitutes the first year. Of these crops only oats, or other grain, can

First year

1	2	3	4
Cultivated crop	Small-grain crop	First-year hay crop	Second-year hay crop

Fields

Second year

1	2	3	4
Small-grain crop	First-year hay crop	Second-year hay crop	Cultivated crop

Fields

Third year

1	2	3	4
First-year hay crop	Second year hay crop	Cultivated crop	Small-grain crop

Fields

Fourth year

1	2	3	4
Second-year hay crop	Cultivated crop	Small-grain crop	First-year hay crop

Fields

FIG. 163. Outline for 4-year rotation. A 4-year rotation may be operated on 4 fields or any multiple of 4, such as 8, 12, or 16 fields. Here 4 fields are represented and the crop that occurs on each field each year is shown. By following such an arrangement of crops, the same acreage of each crop is grown each year.

If more hay is needed, the land can be divided into 5, or a multiple of 5, fields and the hay crop cut an additional year.

Or if more acres of potatoes, or other cash crop, are desired, the area can be divided into 3, or a multiple of 3, fields and thus grow ⅓ more acres of potatoes in a 3- than in a 4-year rotation.

Variations can be made to fit the crops of any part of the country, but once a rotation is decided upon, it must be followed rigidly until the plan is changed.

follow corn; it, therefore, is assigned to the second year of the rotation. The meadow mixture is established in the oats; consequently, clover must occupy the third year of this feed-crop rotation. Timothy,

seeded in the oats, becomes fully established the clover year and is harvested the fourth year. This rotation provides a clover-timothy sod for corn or other cultivated crop. The rotation is (1) corn, (2) small grain, (3) clover, and (4) hay mixture; it is, therefore, a 4-year rotation. This, in general, shows the development of rotations. Some additional details may be discussed under specific rotations for particular areas.

In developing rotations, distance from market and the cost of transportation, whether by wagon or truck on the highway or on the railroad, is sometimes a determining factor. Potatoes, cabbage, and hay are heavy or bulky crops, and transportation over long distances is costly. It is better, therefore, if these crops can be grown within reasonable distances of market. If grain and hay are converted into milk, meat, eggs, or other animal products the transportation cost is greatly reduced.

The adaptation of a crop to the soil and the climate, including rainfall, is of first concern in deciding on a rotation of crops. Another consideration is the lay of the land. If the land is sloping and subject to considerable erosion, a relatively small acreage is properly devoted to soil-exposing crops except with the employment of effective erosion-control measures. In many areas the soil-exposing crops can be grown on the less erodible land and the small-grain, meadow, and pasture crops on the steeper slopes. Another way is to grow only a small proportion of clean-tilled crops in the rotation. This means, as already shown (page 313), that the returns are lower because more of the acreage is in the relatively low-return crops.

3. Choosing Suitable Rotations

In choosing suitable rotations for any agricultural area of the country, the benefits from and the requirements of good rotations are to be borne in mind. Only outlines of important rotations can be given here. More details will be needed, and these can be obtained from the bulletins of the extension service in each state. In the following paragraphs rotations are suggested for important agricultural areas of the country.

For Cotton and Tobacco in the Southeast. Most of the Cotton Belt rotations include legumes that should do much to maintain the organic-matter and nitrogen content of the soil.

COTTON, CORN, SMALL-GRAIN ROTATION[4]

First Year

Spring	Land prepared for cotton
Summer	Cotton
Fall	Winter legume

Second Year

Spring	Winter legume turned under
Summer	Corn, interplanted with summer legume
Fall	Small grain or small-grain—winter-legume combination

Third Year

Spring	Small grain or small-grain—legume combination harvested
Summer	Summer legume for forage
Fall	Land plowed and laid off on contour for cotton, or left in stubble for late winter or late spring plowing

TOBACCO, CORN, PEANUTS, OATS ROTATION

First Year

Spring	Land prepared for tobacco
Summer	Tobacco
Fall	Land plowed for corn

Second Year

Spring	Land prepared for corn
Summer	Corn, interplanted to runner peanuts or velvet beans
Fall	Corn land grazed

Third Year

Spring	Land prepared for peanuts
Summer	Peanuts
Fall	Oats for grain or forage

Fourth Year

Spring	Oats cut for grazing or forage
Summer	Weeds and grass
Fall	Land plowed for tobacco

THREE-YEAR COTTON, FORAGE, CORN ROTATION

First Year

Spring	Seedbed preparation for cotton
Summer	Cotton
Fall	Winter legume and small grain

Second Year

Spring	Winter legume and grain, grazed or cut for hay
Summer	Summer legume for forage
Fall	Winter legume

Third Year

Spring	Winter legume turned under
Summer	Corn planted with summer legume
Fall	Land plowed for cotton

By seeding winter oats or barley alone after cotton (first year), grain may be harvested the second year.

[4] ALEXANDER, E. D., Austrian Winter Peas and the Vetches, *University of Georgia Extension Bulletin* 453, 1939, pp. 19–24.

This 3-year rotation can easily be changed to a 2-year cotton-corn rotation by seeding corn the second year instead of the indicated "summer legume for forage."

Many other rotations are used in the Cotton Belt, but these show the great extent to which legumes are used in the South. And such use of legumes is highly desirable for helping to keep up the supply of nitrogen and active organic matter in the soil. Maintenance is difficult in the long frost-free period of this section.

For the Great Plains. For eastern Kansas, Salmon and Throckmorton[5] recommended:

	I	II
First year	Corn	Corn
Second year	Corn	Corn
Third year	Oats	Oats
Fourth year	Sweet clover	Wheat
Fifth year	Wheat	Red clover

If clover hay is needed for feed, arrangement II above is suggested.

For less productive soils the following order is practiced: (1) corn seeded with lespedeza, (2) oats, (3) sweet clover, (4) wheat, and (5) red clover. Legumes in 2 out of 5 years with volunteer lespedeza supply sufficient organic matter and nitrogen.

For central Kansas, Laude and Swanson[6] suggest a 4-year rotation of:

First year	Sorghum
Second year	Barley or oats
Third year	Wheat
Fourth year	Wheat

It may be noted that no legumes are in this rotation. This rotation, however, is for the area that is drier and where the soils have been leached less than to the eastward. The soils of this area, therefore, are well supplied with plant food.

Southern Great Plains. In the Great Plains, saving and conserving water is the farmer's most pressing problem. A rotation that makes

[5] SALMON, S. C., and R. I. THROCKMORTON, Wheat Production in Kansas, *Kansas Agricultural Experiment Station Bulletin* 248, pp. 11–17, 1929.

[6] LAUDE, H. H., and A. F. SWANSON, Sorghum Production in Kansas, *Kansas Agricultural Experiment Station Bulletin* 265, pp. 39–40, 1933.

good use of the available moisture is (1) wheat, (2) grain sorghum, and (3) fallow.[7] This rotation is best used on medium- to fine-textured soils that are not subject to serious wind erosion. The low rainfall prevents the use of legumes as in humid areas.

Although following a specific rotation is desirable wherever possible, wheat is not to be seeded unless the soil contains sufficient water at seeding time. There should also be enough trash to help in the control of soil movement by the wind.

Eastern Oklahoma. For the northeastern part of the state, rotations that include grains and legumes are grown. Such a rotation is (1) small grain, seeded to sweet clover, (2) sweet clover, and (3) corn. Corn may be repeated, making a 4-year rotation.

A shorter rotation is (1) soybeans followed by winter barley, (2) winter barley seeded to lespedeza. Such a rotation should maintain the nitrogen and organic matter of the soil.

For the southeastern part of the state, cotton and peanuts are included in rotations. On the better soils the rotation may be (1) cotton, (2) oats with lespedeza, cowpeas, or mung beans, and (3) corn, with cowpeas, (alternate-row effect).

Kafir may be used instead of corn or cotton on less productive soils. A suggested rotation is (1) oats, sweet clover, (2) sweet clover, (3) corn, and (4) cotton or peanuts on sandy soils.

For the Corn Belt. For the extensive corn-growing area three 4-year rotations are used:

	I	II	III
First year	Corn	Corn	Corn
Second year	Corn	Oats	Soybeans
Third year	Oats	Clover	Oats
Fourth year	Clover	Timothy or other grass	Clover

Rotation I with only 1 year of corn makes a common 3-year rotation. Rotation II fits the thinner soils or cooler temperatures where dairying or beef production are important enterprises. Rotation III is used in order to diversify further, and using wheat or winter barley instead of oats would increase income wherever the soybean crop can be harvested in time for seeding these winter grains.

[7] CHAFFIN, WESLEY, A Soil Improvement Program, *Oklahoma Extension Circular* 412, 1945.

Etheridge and Helm[8] recommend 2 rotations:

	I	II
First year	Corn	Oats
Second year	Oats	Wheat
Third year	Wheat	Winter barley
Fourth year		Rye

In rotation I, Korean lespedeza is seeded in the wheat and it is well established after that. Self-seeding keeps a stand of it coming on each year. Likewise, Korean lespedeza is in the oats in rotation II. It makes enough growth to supply nitrogen for the grain crops. Grain can be produced at low cost per bushel by this method.

Rather reports on a 5-year rotation for erodible sandy land in Michigan.[9]

First year, corn for grain, seeded to sweet clover in corn about 24 inches tall
Second year, corn for silage, seeded to alfalfa and smooth brome grass
Third year, alfalfa—smooth brome grass } for hay or pasture
Fourth year, alfalfa—smooth brome grass } for hay or pasture
Fifth year, alfalfa—smooth brome grass } for hay or pasture

Sandy land must be well supplied with manure, phosphorus, and potash. A very important point is that the soil has an erosion-resisting cover on it every winter. This idea may well be followed in other areas.

For the Northern Wheat Belt. Hutton[10] reported on the use of a rotation of (1) corn, (2) oats, (3) wheat, (4) barley, and (5) red clover, and another in which the oat crop is switched to the fourth year and wheat and barley are moved forward. Because these are all grain crops, little difference in results should be expected. A reason for such meager use of leguminous crops may be that they draw heavily on the small supply of water in this area.

For the Dairy-farming Area. Rotations for the dairy-farming area may be simple, 3-, 4-, or 5-year rotations. Three-year ones are usually (1) corn, (2) oats, and (3) clover. An ordinary 4-year one simply includes an additional year for hay, mostly timothy. In fact,

[8] ETHERIDGE, W. C., and C. A. HELM, Korean Lespedeza in Rotations of Crops and Pastures, *Missouri Agricultural Experiment Station Bulletin* 360, pp. 6-12, 1936.

[9] RATHER, HOWARD C., "Field Crops," McGraw-Hill Book Company, Inc., New York, 1942.

[10] HUTTON, J. G., Thirty Years of Soil Fertility Investigations in South Dakota, *South Dakota Agricultural Experiment Station Bulletin* 325, 1928.

this rotation is often one of 5, 6, or 7 years by continuing to cut the hay produced. Under favorable soil conditions, (1) corn, (2) oats and/or barley, (3) alfalfa and timothy or brome grass, and (4 and 5) alfalfa are grown as a 5-year rotation. It is probably desirable to limit this rotation to a period of 5 years; otherwise it will be difficult to work out the acreages so as to produce approximately the same quantities of feed each year.

In parts of this area, potatoes are substituted for corn or part of the corn acreage. This change is desirable if the feed supply can be provided, because in a climate and soil adapted to them potatoes are a good cash crop within reasonable distances of markets. Moreover, much of the dairy area needs a cash crop to improve the economic diversification on dairy farms. In some sections, cabbage or beans may occupy part of the cultivated acreage to advantage.

For Cash-crop Areas. For strictly cash-crop areas, the rotation may be shorter than in dairy-farming areas because cash-crop areas need little hay. There is, however, real need for maintaining the active organic content of the soil. Without hay crops this is more difficult of accomplishment. In western New York, farmers are producing mainly cash crops, although many of them do feed lambs or steers in winter to use up roughage. A rotation possibility is (1) potatoes, sweet corn, cabbage, tomatoes; (2) beans; and (3) wheat. Wheat is seeded after beans, without plowing. Disking or spring-tooth harrowing produces the necessary seedbed for wheat. Sweet clover comes on after the wheat is harvested and makes good growth under favorable soil conditions and with sufficient rainfall. Sweet clover makes the type and approximate quantity of growth that is indicated in Table 26 on page 259. Sweet clover, thus grown, produces important quantities of organic matter and fixes large quantities of nitrogen, both of which aid greatly in maintaining the productivity of the soil. Other field-grown vegetables such as beets, carrots, cannery peas, market peas, or lima beans can be grown in a similar rotation. Peas may be substituted to financial advantage for the wheat in this rotation and may serve as nurse crop for sweet clover or alfalfa.

For the Kentucky Tobacco Area. Two rotations for Kentucky are recommended by Roberts.[11] Both are 3-year rotations.

[11] ROBERTS, GEORGE, Soil Management for Kentucky, *Kentucky Agricultural Experiment Station Extension Circular* 272, pp. 47–48, 1934.

	I	II
First year	Tobacco	Corn
Second year.	Wheat	Wheat
Third year.	Clover	Clover

If all the land is well adapted for tobacco production, these rotations may be alternated, or, in reality, it will then be a 6-year rotation. Tobacco will be most heavily fertilized. The advantage, therefore, in alternating the two 3-year rotations is to make the best use of the residual fertilizer from the tobacco crop. Because the soil is exposed for only short periods, these rotations protect the soil fairly well from erosion.

SUMMARY

1. Crop rotation is the growing of crops in the same order over a period of years. Clean-cultivated crops may be grown in regular order, but this would not be a good rotation. Good rotations, at least in the northern part of this country, have a year of leguminous hay crops and usually one or more additional years of mixed legumes and grasses for hay or pasture. In addition, one clean-cultivated crop is grown, followed by a small grain in which the hay crops are sown. The leguminous hay crops may be regarded as the essential part of the rotation.

2. Rotating crops increases the yield of the clean-cultivated crop and, usually, the average value of crops produced over a period of years.

3. With a regular rotation of crops a fairly uniform acreage of each crop is grown every year.

4. Rotating crops helps in the control of both annual weeds and perennial ones that infest meadows. Similarly, rotation helps in the control of insects and plant diseases. This is accomplished by changing the crop. Most insects and diseases do not attack all of the crops of the rotation to the same extent; they may starve and die out in the absence of their particular food crop.

5. Crops feed in different ways or their roots occupy different zones in the soil. Rotation, therefore, gives a better growth than keeping one crop on the same soil year after year.

6. Rotation helps in keeping up the organic-matter content of the soil and thus improves the tilth of the soil and, as a consequence, helps in the control of soil erosion.

7. It is important to choose the right rotation for each section of the country and for each important cash crop. Tobacco is grown in rotation

with certain crops in North Carolina but with entirely different crops in Wisconsin or New York.

8. Similarly, corn is grown in rotation with certain feed crops in Iowa and Missouri but with different ones in Mississippi and Georgia.

9. The rainfall of an area affects the rotation. A good rotation with wheat in the Great Plains is different from a good wheat rotation for the limited production of this food crop in Ohio or Indiana.

10. Leguminous crops are the key to good rotations in the humid sections of this country. In the drier areas, legumes deplete the soil of moisture to an undesirable degree and are, therefore, less useful than in humid areas.

13. Managing Pasture Soils

ABOUT half of the land in farms in the United States is used for pasture. Some of it is excellent pasture, some is woodland pasture of low productivity, and a larger proportion is stony, rough land or land that receives too little rainfall to produce much pasturage. In the eastern part of the United States and along the Pacific coast the grasses are largely introduced plants, but the range grasses are mainly native ones.

Good pasturage is essential in the economic production of livestock and livestock products. The least expensive gains of meat animals and the most economical production of milk, eggs, and wool are on pasture. No human labor is required to do the actual harvesting of pasture. This condition is in marked contrast to the making of hay, ensilage, or the harvesting and storing of grain. This chapter is confined mainly to the handling of soils, seeding methods, and fertilization of pasture lands which are discussed under the following activity headings:

1. Handling Unplowable Permanent Pastures
2. Handling Plowable Pasture Land
3. Establishing New Long-term Pastures
4. Managing Poorly Drained Pasture Land
5. Treating Muck-land Pastures
6. Burning Pastures in the Spring
7. Grazing Pasture Lands

1. Handling Unplowable Permanent Pastures

Pastures may be regarded as unplowable for several reasons; Some have ledges of bedrock so close together, or the soil is so thin over bedrock, that plowing is not practicable. In other areas, there are so many boulders that plowing between them is not feasible. In some sections there are outcrops of bedrock with large blocks of rock scattered about over the surface. Slopes in many places are too steep or the land too rolling for plowing. Combinations of two or more of these conditions are found in some areas.

Some lands are too lacking in productivity to warrant any expenditure of labor or the application of fertilizer or seed. The least productive of them may be reforested or the livestock fenced out and natural reforestation permitted to take place in sections where that occurs. An alternative is to graze dry and young stock or sometimes sheep and goats on such areas for a time. The areas may then be abandoned. Farmers or stockmen who have used these lands are under obligation to see to it that they are not a menace to other lands. If serious erosion is certain to follow or if flash runoff will flood lower-lying inhabited areas, provision must be made to avoid these disastrous conditions.

Mowing Brush and Weeds. Brush and weeds usually lower the production of feed on unplowable pastures. If the prospects are good enough, start improvement with mowing the brush and weeds. Destroying them by grazing the area with goats may be feasible if the land is too rough for mowing with the usual machinery. Hand mowing may be restored to, but the task is rather laborious and time-consuming. Much will depend on the cost of removing the brush and weeds. Unless the soil is productive, the expenditure of labor may not be warranted.

Using Lime. If leguminous plants do not grow because of high acidity, liming is essential. Use limestone, if spreading can be done with the usual spreading implements. The most concentrated form of lime (ground, burned, high-magnesium lime) can be hand spread, but that is seldom done at the present time.

Using Phosphorus. Many pastures in this group lack available phosphorus in the root zone of pasture plants. To obtain improvement, therefore, apply phosphorus (Fig. 164). Several forms are available for this purpose. On acid soils, heavy applications of basic slag supply not only phosphorus but lime that reduces the acidity. On some soils this enables white clover or other legumes to make good growth. Rock phosphate, finely ground, serves the same purpose in the same way but is slow in its action. Superphosphate supplies available phosphoric acid and sulphur and may be the best to use on soils that are of slight acidity or that have been limed. In Northern areas, applications of phosphorus alone are unlikely to increase the production of feed until legumes come into the pasture sward. On sandy soils, particularly those of the southeastern Coastal Plain, phosphorous markedly increases pasture yields.

Using Potash. If the soil is deficient in potash, this may be put on in muriate of potash or in the mixed fertilizers already mentioned. If put on alone, the 60 per cent muriate or potassium metaphosphate may be used to advantage. This is particularly true if hand spreading is necessary.

Using Complete Fertilizer. Complete fertilizer may be used. If it is to be spread by hand, and that is feasible on rough or stony land, use the highest concentration available. This, of course, applies to any material that is to be hand spread. Nitrophoska, a 15–30–15 fertilizer, which was on the market some years ago, is suitable; 100 pounds of it

FIG. 164. Fertilizing rough or stony pastures. A concentrated fertilizer can be spread on pastures that are too steep, stony, stumpy, or rough for spreading lime or fertilizer with machinery. Here a 15–30–15 fertilizer is being spread with a cyclone seeder. E. V. Staker at the right, the writer at the left, fertilizer bags in the right background. (*A. R. Blanchard.*)

are equivalent in fertilizing value to 300 pounds of 5–10–5, and applying 100 pounds by hand is not too laborious. Until something of like concentration can be obtained, uramon may be mixed with potassium metaphosphate to make a concentrated product for hand spreading. Mix equal quantities of uramon and potassium metaphosphate to produce a mixed fertilizer that contains 21 per cent of nitrogen, 30 per cent of phosphoric acid, and 20 per cent of potash, or a 21–30–20 fertilizer. All of its plant food is readily available to crops. Mixing these materials as they are spread is a safe procedure.

Using Manure. If manure can be spared from the cropland, its use on pastures is usually beneficial. It supplies nitrogen, phosphoric

acid, and potash. Supplementing it with phosphorus is usually highly beneficial. Manure protects the soil and young plants until they become well established. Moderate rates of application stimulate the growth of both legumes and grasses.

Disking and Harrowing. Both lime and fertilizer are more effective if they are mixed with the surface soil. Use the disk or spring-tooth harrow for this purpose if rock ledges and boulders are

FIG. 165. A mixture of wild white clover and Kentucky bluegrass in New York in July. This is an old pasture that has had no treatment. Yet with sufficient moisture, the grass and clover are at a good height for grazing.

not too close together. If no mixing with the soil is feasible, make a surface application. A longer time will then be needed for most of these materials to become effective. The uramon and potassium metaphosphate, however, are taken up by plants as soon as they are dissolved in the soil moisture.

Seeding. Seed the more desirable pasture plants if they are not in the sward. Sow seed of the grasses and legumes that thrive in your locality on the surface early in the spring. These grasses and legumes will usually be the best investment. Use the commonly recommended rates of seeding for your locality (Fig. 165).

Wisconsin Pasture-improvement Plan. In Wisconsin,[1] bluegrass pastures have been improved by mixing lime and fertilizer with the soil and seeding legumes. The steps are: (1) Test the soil. (2) Put on limestone, phosphorus, and potash too, if a need is indicated. (3) In the early spring when the sod is dry enough to work, go over the land with disk or spring-tooth harrow or field cultivator. This mixes the lime and fertilizer material with the surface soil, but not so deeply as is possible where the land is plowed. (4) Level the soil with a peg-tooth or spike-tooth harrow. (5) Unless weeds are a serious problem, sow 10 pounds of alfalfa or 12 pounds biennial white sweet clover and 5 of red clover with 3 or 4 pounds of timothy. (6) Cover the seed lightly or pack with the cultipacker the sod that remains alive. This covers the seed and may save some of the bluegrass to hold the soil against washing until the new seeding becomes established. (7) Fence livestock off the treated area until the seeding is well started so that grazing may not kill the young seedlings. The use of inexpensive but reliable electric fence reduces the labor required for this purpose.

Fertilizing the land and obtaining good stands of these deep-rooted legumes has doubled the production on these pastures. The rapid, tall growth of alfalfa and sweet clover crowds out the weeds. These legumes also control the white grub. Moreover, in addition to supplying a large quantity of feed that is high in both minerals and the ordinary nutrients, the legumes gather much nitrogen. This is used by the grasses that grow along with the legumes. In addition, these mixtures completely control erosion.

2. Handling Plowable Pasture Land

Plowable pastures occupy about one-fifth of the total pasture land, including woodlands and range pastures. This fifth, however, is an extremely important fraction of the pasture land of the country (Fig. 166). It is highly productive and is usually accessible to the farmstead. The management of the plowable pasture land varies with the pasture cover, the slope of the land, and the soil.

Improving a Poor Stand of Good Pasture Plants. A few representative seeding mixtures for pastures are given on pages 331 to 337. Most of the state extension services have published recommendations

[1] Burcalow, F. W., and G. Bohstedt, Plan Wisconsin Pastures, *Wisconsin Extension Circular* 298, 1940.

for pasture-seeding mixtures. Many of them vary only slightly from those of near-by states. There are many soil and moisture conditions that govern the type of mixture to be used. Moreover, take into consideration whether the pasture is to be permanent, temporary, or only for aftermath grazing in meadows.

Reseed. Plowable pastures that have a poor stand of good pasture plants require reseeding for quick results. Often it pays to plow and prepare a good seedbed for reestablishing pastures. If the pasture is not required the same year it is plowed, a clean-tilled crop may be

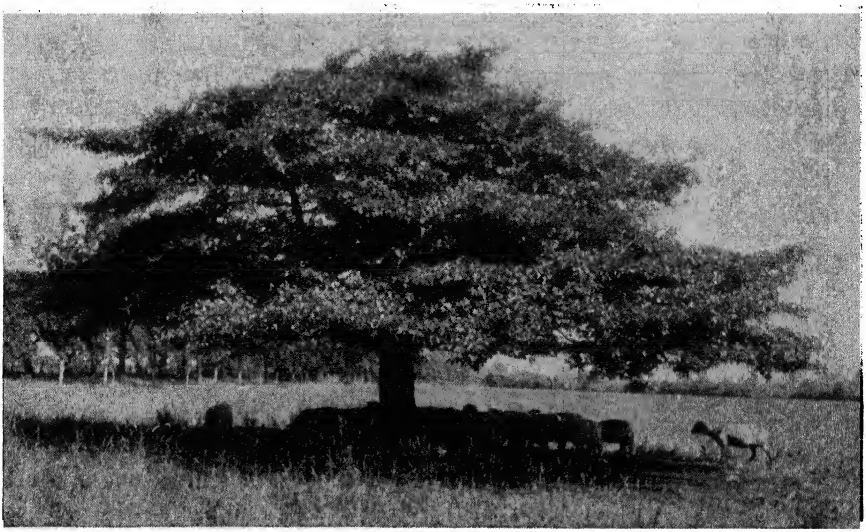


FIG. 166. Sheep in the protecting shade of an old hawthorne tree. The sheep are well fed on this bluegrass-timothy-clover pasture. Shade is essential on hot days, particularly in July and August, even in the latitude of central New York.

grown. This will help to bring pasture weeds under control. Reseeding may be done at once, but it requires considerable work to produce a firm seedbed. Work the sod down well and roll to close any large holes that cause drying out of the soil. The seeding can then be made and covered lightly with a peg-tooth harrow or weeder. If the pasture is needed the same season, seed oats or barley, sow the pasture mixture after the oats, and cover lightly. The oats then serve not only as nurse crop but are grazed off by livestock. After the oats have been used, it may be necessary to take the cattle off the land for a while to let the seeding become well established before regular grazing.

Plow Slopes in Contour Strips. Long, steep slopes are advantageously plowed in contour strips about 100 feet wide with an equal width of strip unplowed. On the more erosive situations it may be wise to take 4 years to reseed. First year, plow alternate strips 100 feet wide on the upper half of the slope and reseed them as suggested in the preceding paragraph. Second year, plow and seed alternate strips on the lower half of the pasture. Third year, plow and seed the strips on the upper half that were left untouched 2 years earlier. Fourth year, plow and reseed the remaining strips on the lower half of the pasture. On less steep and shorter slopes of less erodible pastures, it may be entirely safe to plow and reseed alternate 100-foot strips on the entire pasture. Wherever the latter procedure is safe it has the advantage of getting a pasture-renovating job done in 2 years. Under these conditions, grazing off the oat crop is the easiest way of keeping the livestock supplied with good grazing much of the season.

Use Limestone Liberally, if Needed. Test the soil for lime requirement. If 1 ton of limestone is needed for red clover, however, it may be wise to put on 2 tons. Put 1 ton on immediately after plowing if an intertilled crop is to be grown. Then put on another ton when the soil is plowed or otherwise prepared for oats. With this method the limestone is mixed with all the plowed soil. This mixing encourages deeper growth of shallow-rooting legumes and is necessary for alfalfa. If reseeding is to be done without an intertilled crop, put all the lime on after plowing. One ton rather than two is probably advisable, because reseeding will likely be necessary in 5 or 6 years. There may be a decided advantage in using somewhat coarser limestone than is used in the East. Limestone meal or fine screenings, such as those that are used in the Middle West, may be superior to finely ground stone for pastures. Enough of them should be used to produce clover. The advantage is that the coarser particles will remain in the soil a long time, and while they last they serve as centers of alkalinity and sources of calcium for the growing pasture plants, particularly the legumes. If the soil test shows that alsike clover might be expected to grow moderately well, liming may be omitted because of the outlay involved. On the other hand, the fact that an abundance of lime may improve the actual feeding value of the herbage is not to be overlooked.

Use Phosphorus Freely. In the East, Southeast, and Southwest, superphosphate is most widely used as a source of phosphorus.

Because there is a chance to mix the superphosphate with the soil, a liberal application may be made to advantage before reseeding. Surface application is far less effective. Putting on 100 pounds or even more of actual phosphoric acid or the equivalent of 500 pounds of 20 per cent, 550 pounds of 18 per cent, or 250 pounds of 40 per cent superphosphate is advisable. Such an application will help the pasture greatly for a period of 4 or 5 years and usually pays well for the investment.

In the Southeast there may be a real advantage in applying basic slag which is produced in the Birmingham steel-producing area. Slag can be used on acid soil because it corrects acidity without other liming. A thousand pounds or even a ton to the acre, mixed with the plowed soil, should prove a good long-term investment. Slag supplies phosphorus and calcium and also iron and other elements that crops use in growth. One reason for using it in this region is that the cost of transportation is low because of the short distance from the place of production.

Likewise, finely ground rock phosphate may be used in similar quantities to the acre in the Middle West. Mixing rock phosphate with manure or green plant material and the soil gives best results. Legumes can make good use of phosphorus in rock phosphate. Surface application of rock phosphate is not recommended because of its slow action. Without clover, these phosphatic materials cannot be of much benefit to pastures. Like slag, rock phosphate can be used on moderately acid soils without limestone. In fact, it becomes available more readily in acid than in alkaline soils. There is no objection to the use of superphosphate in the Middle West. Yet the cost of actual phosphoric acid is much lower in rock phosphate than in superphosphate, at least within a reasonable distance of the rock-phosphate fields in Tennessee. Rock phosphate, however, is rated as being relatively slow in its action in the soil.

All of these carriers of phosphorus are likely to contain more or less of the minor elements in which some soils are deficient. Liberal use of these phosphates should improve the feeding value of the pasturage for the livestock. They, in turn, retain and put into meat, milk, eggs, and other products the additional food values that man needs for proper nutrition.

Use Potash on Sandy or Depleted Soils. Sandy and gravelly soils are often deficient in potassium. This element is most economically applied in much of this country as 60 per cent muriate of potash.

Areas close to sources of alcohol wastes, "vegetable potash," may find it economical to use. Like phosphorus, potash gives quicker and better results if mixed with the soil than if put on the surface. Clovers and other legumes make good use of potassium and pay well for it where the soil is low in available potash. Potassium metaphosphate and mixed fertilizers also supply both potash and phosphorus, and mixed fertilizers supply some nitrogen in addition.

Manure to Improve Pasture and to Check Erosion. Manure, as already stated, supplies all three fertilizer elements, and organic matter. Manure, however, needs supplementing with phosphorus in an economical form. Any of the three forms discussed can be effectively used with manure. Especially when put on as a surface dressing after seeding a pasture mixture, manure helps in getting a stand and protects the soil to some extent against erosion by water or by wind on sandy soils.

Cattle graze freely if manure other than that of cattle is used, and the same is true of many animals. They avoid grazing on pasture that is treated with manure from their own type of animal. Advantage may be taken of this fact for protecting new seedings in old pastures, such as strip-seeded pastures. Even a light dressing is helpful for all of these purposes during the season in which it is applied.

Improving the Stand of Pasture Plants. Treatment for pastures that have good stands of desirable grasses and legumes may be applied on the surface with good results. This treatment, however, is slower than that which is mixed with the soil. Treatment of established swards is limited to surface dressings of lime and fertilizers. Treatment similar to that outlined on the preceding pages for poor stands is generally suitable. An exception is made with rock phosphate, which probably should always be mixed with the soil. Basic slag is more effective if mixed with the soil, but benefits should follow surface application.

Repeating Lime and Fertilizer Application. On acid soils it will be necessary to repeat the liming every 5 years or more, depending on the rate of application used and the fineness of the material. Likewise, repeating the application of phosphorus is essential. This varies with the rate used. Superphosphate is needed at an average rate of about 100 to 150 pounds of 20 per cent superphosphate a year, and basic slag or rock phosphate at about double these rates. Manure

may be used according to the supply available for pastures. Applications of 6 or 8 tons an acre every 2 to 4 years will help the herbage very markedly.

Scattering the Droppings. The droppings should be scattered once a year. A peg-tooth harrow can be used on fairly smooth land. A chain or flexible harrow or a brush harrow serves this purpose. Some farmers have bolted used automobile rims together in two or more rows and dragged them over the pasture like a harrow. Any of these ways of spreading the droppings is satisfactory. The main idea is to distribute the fertilizing value of the droppings to get more growth out of them.

3. Establishing New Long-term Pastures

Careful planning is essential for establishing new long-term or permanent pastures. The feeding value of the herbage will depend on how well all needs of the pasture plants have been supplied. If lime is needed for the legumes that are to be used, it should be applied freely and mixed thoroughly with the plowed soil. The use of some coarse limestone will increase the length of time that it can supply the needs of the pasture plants. Phosphorus, which is deficient in most of the humid pasture area except the famous bluegrass region of Kentucky, may well be applied liberally before seeding, when it can be mixed with the soil. On lands known to be deficient in potash, this may be put on in a moderate application, or manure may be put on at regular short intervals. Following these suggestions should ensure a productive pasture.

Choosing Seeding Mixtures. For Oklahoma, Osborn[2] recommends the following:

For Northeast Oklahoma—Fertile Well-drained Soils	
Orchard grass, Kentucky bluegrass, timothy and lespedeza—each	4 to 6 pounds an acre
Alsike, white Dutch, and hop clover—each	1 to 2 pounds an acre
For Southeast Oklahoma—Good Upland Soils	
Bermuda grass	Sod pieces
Dallis grass. . .	4 to 6 pounds of seed an acre
Lespedeza	5 to 10 pounds of seed an acre
Hop clover	1 to 2 pounds of seed an acre
For Western Oklahoma	
Bermuda (spring planted) . . .	Sod pieces
Sweet clover (early September)	4 to 6 pounds of seed an acre

[2] Osborn, L. W., Crop Adjustments, *Oklahoma Agricultural and Mechanical College Circular* 307, 1935.

FIG. 167. Bermuda grass and lespedeza pasture in Louisiana. This pasture is on a 10 per cent slope of worn-out, once badly eroded cotton land. The land has been terraced and limed and fertilized. Now it produces good yields of beef. (*C. I. Bray, Louisiana Agricultural Experiment Station.*)

FIG. 168. Persian white clover-Dallis grass pasture. This pasture is in upland Coastal Plain flat woods in southeast Louisiana. The mixture is Persian white clover and Dallis grass. The land has been treated with 1½ tons of limestone to the acre and phosphorus and potash. The treatment has been profitable for the farmer. (*D. L. Bornman, Jr., Mississippi Agricultural Experiment Station.*)

Ryegrass is highly regarded for fall, winter, and spring grazing and Korean lespedeza for summer. Wheat, winter barley, and winter oats furnish considerable pasturage.

Varieties of Bermuda grass (Fig. 167) head the list of pasture grasses for Oklahoma. They are planted as pieces of sod in furrows 4 feet apart, with 10 pounds of lespedeza and 5 to 8 pounds of Dallis grass seed to the acre (Fig. 168). Brome grass is very promising for pasture in Oklahoma and is widely used to the northward and

FIG. 169. A mixture of smooth brome grass and alfalfa in Nebraska. For soils and climate to which alfalfa and brome grass are adapted, this mixture supplies high-grade pasturage. (*Soil Conservation Service, U.S. Department of Agriculture.*)

considerably to the eastward. White clover, alsike, red clover, alfalfa, sweet clover (presumably biennial white), and black medic all are used for grazing purposes in Oklahoma.

Buffalo grass is widely used for pasture in the Great Plains. A few pieces of sod to the acre planted in the spring, and seeds that are spread by livestock often produce a full stand in 3 years.

Brome grass is an especially valuable pasture grass in Nebraska, in adjacent states, and in those to the eastward (Figs. 169, 170, and 171). Seed production is centered about Kansas, Nebraska, and Iowa.

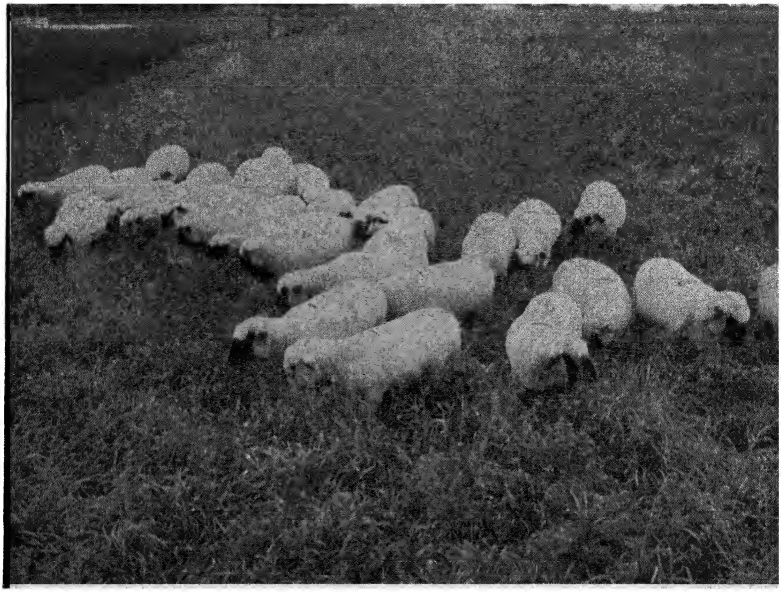


FIG. 170. Sheep on brome grass-alfalfa pasture. Sheep make excellent gains on this pasture mixture. (*Soil Conservation Service, U.S. Department of Agriculture.*)

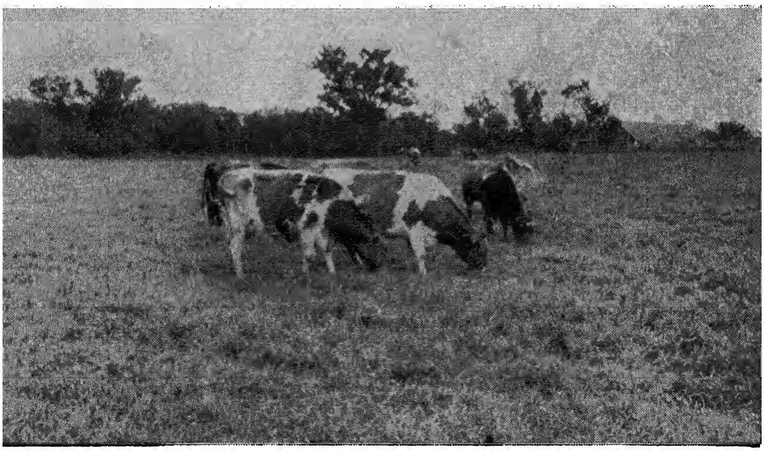


FIG. 171. Dairy cows on brome-grass pasture in Nebraska. In its area of adaptation, brome grass with a tall-growing legume such as alfalfa produces large quantities of excellent feed. (*Soil Conservation Service, U.S. Department of Agriculture.*)

The following seeding mixtures are recommended by Frolik and Frolik for eastern Nebraska and under irrigation:

MIXTURE I FOR AVERAGE CONDITIONS[3]

	Pounds of Seed to the Acre
Brome grass	15
Alfalfa...	3
Total per acre	18

MIXTURE II FOR QUICK PASTURE PRODUCTION IN FAVORABLE SEASONS

Brome grass.	10
Timothy	4
Alfalfa.......	2
Sweet clover..	2
Total per acre..	18

MIXTURE III FOR THE MOST FAVORABLE GROWING CONDITIONS

Kentucky bluegrass	10
Timothy.	5
White clover...	2
Total per acre...	17

MIXTURE IV MAY BE USED ON THE UPLANDS OF THE WESTERN PART OF THE STATE

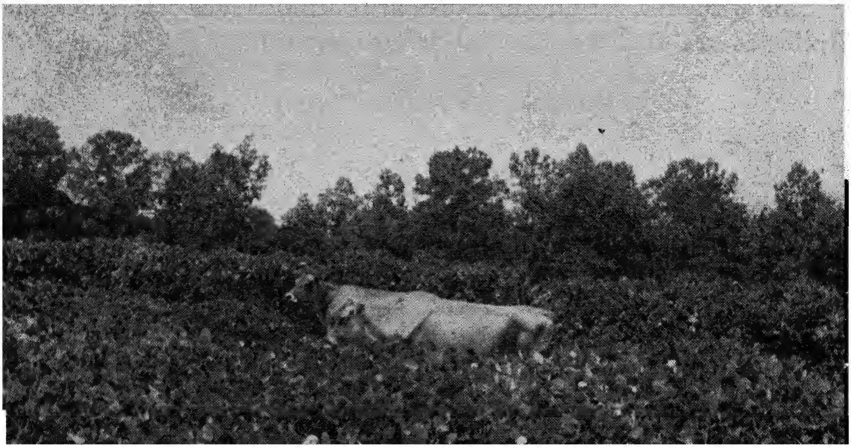
Western wheat grass	5
Crested wheat grass	4
Brome grass.	3
Total per acre...	12

For the South generally, varieties of Bermuda grass are regarded as the best pasture grass. Carpet, Dallis, and varieties of Bahia grass also are grown on large acreages. White clover, lespedeza, or other legume is needed in mixtures not only by grasses for the nitrogen it fixes, but for its feeding value to the grazing animals. Ten to 12 pounds of common, or 18 to 20 pounds of Korean lespedeza to the acre are used. Lespedeza dies down in late summer; other pasturage, therefore, is needed for the rest of the pasture season (see Fig. 172).

Most varieties of Bermuda grass are established from pieces of sod, but the other grasses are seeded, 5 to 10 pounds to the acre.

For winter pasture, rye grass and adapted legumes may be established in meadows, 20 to 30 pounds of ryegrass seed to the acre being used. Rich land is best for this grass. Small grains, especially rust-

[3] FROLIK, A. L., and E. F. FROLIK, Nebraska Pastures—Seeding and Management, *Nebraska Agricultural Experiment Station Circular* 67, 1941. See also FROLIK, A. L. and L. C. NEWELL, Bromegrass Production, *Circular* 68.



thrifty growth of kudzu. Being a legume, inoculated kudzu makes good growth even on severely eroded soils. Kudzu not only is a nourishing forage, but it checks erosion and improves the soil. (*G. D. Sturkie, Alabama Agricultural Experiment Station.*)

resistant oats, afford much late-winter and spring grazing under favorable conditions.

Alexander[4] recommends the following pasture-seeding mixtures for Georgia:

COASTAL-PLAIN REGION

Lowland

	Pounds (per acre)
Lespedeza (common)	12 to 15
Dallis grass	6 to 8
Carpet grass	4 to 6
White clover	2 to 3

For upland, Dallis grass is omitted and hop clover replaces white clover.

PIEDMONT REGION

Lowland

Lespedeza (mixture of varieties)	10 to 15 pounds
Dallis grass (high germination)	6 to 8 pounds
White clover	2 to 3 pounds
Bermuda grass	Rootstalks

For upland, white clover is replaced by hop clover and Dallis grass is omitted.

[4] ALEXANDER, E. D., Pastures for Georgia, *University of Georgia, Extension Bulletin* 457, pp. 16–17, 1942.

LIMESTONE VALLEY AND UPLAND REGION

Upland

Lespedeza (mixture of varieties)	12 to 15 pounds
Bermuda grass	Rootstalks
Bluegrass	3 to 5 pounds
Hop clover	3 to 5 pounds

For lowland, 3 to 5 pounds of herd's-grass (redtop) and 6 to 8 pounds of Dallis grass are added and bluegrass and hop clover are omitted.

Redtop is useful on wet lands of the upper South.

Kentucky bluegrass is used throughout the humid part of the North and into the upper South and still farther southward in the mountains.

Sudan grass is most widely used for supplemental pasture.

For the North and Northeast the following mixture is used for grazing only.

	Pounds to the Acre
Kentucky bluegrass	8
Redtop	3
Timothy	5
Perennial ryegrass	5
Wild white clover	1

Ryegrass makes an immediate cover, and the close grazing that is suited to this clover and Kentucky bluegrass soon crowds out everything else. Wild white clover and Kentucky bluegrass work well together throughout the North and as far south as the latitude of northern North Carolina on the lowlands and farther south on higher elevations. Sow 1 pound of wild white clover with from 5 to 15 pounds of Kentucky bluegrass. The amount to use varies with the seeding mixture and whether the crop is to be cut for hay a year or more before grazing it. Kentucky bluegrass is somewhat slow in establishing itself. Close grazing is essential in order to keep white clover growing. Shading often kills this clover.

For Michigan, Rather[5] recommends a mixture of 8 pounds of alfalfa and 7 of smooth brome to the acre. The brome seed may be distributed after mixing it with the grain. Alfalfa should last from 3 to 5 years. This mixture remains palatable longer than most pasture plants.

Ladino is sown at rates of 3 or 4 pounds to the acre with grasses other than sod formers. Less seed may be used under favorable conditions. It is crowded too much by turf formers like Kentucky

[5] RATHER, HOWARD C., "Field Crops," McGraw-Hill Book Company, Inc., New York, p. 196, 1942.

bluegrass and redtop. Four or five years of grazing may be expected from a seeding of Ladino clover.

Fertilizing Pastures with Nitrogen. In pastures and in meadows, legumes gather nitrogen and produce feed that is well supplied with protein, phosphorus, calcium, and other essential minerals. Grass, even if heavily fertilized with nitrogen, cannot supply these minerals satisfactorily. A heavy application of nitrogen in the spring increases the already high peak of growth when livestock cannot keep up with growth, yet the nitrogen does little to maintain production in July and August when growth is nearly, or entirely, at a standstill. A heavy supply of nitrogen depresses the growth of legumes by shading during the period of lush growth. Actually more feed has been produced by legumes and grasses that were supplied with lime and phosphorus than by the same plant mixture with a liberal supply of fertilizer nitrogen and phosphorus.

Dairy cows make best milk production on lush green grass mixed with legumes. Beef cattle, sheep, and young stock are less exacting. They might consume mature grass and make good use of it. Even if they do, much feed is wasted by trampling it down when animals are turned into green feed that is 2 or 3 feet tall. Getting as much as possible off the pasture is probably more economical than making hay of it and later feeding the hay to the stock during the pasture season.

The country has an enormous capacity for the production of synthetic nitrogen. Even so, it cannot be very cheap when it is delivered to the individual farm. Much handling and transportation is expended on it, to say nothing of several legitimate profits between the big synthetic-producing plant and the farmer's pasture. The cost of heavy nitrogen treatment, therefore, is high. The low cost of obtaining nitrogen, without labor other than supplying phosphorous and lime in abundance, is an advantage from growing legumes in pasture and meadow mixtures that must not be overlooked by the farmer. The better feed in legume-grass mixtures than in grass alone is a matter of first concern to the stockman. It is no less a concern of the consumer of the animal products, because the animal passes on in the meat, milk, and other products these minerals that are so vital to proper nutrition in man.

4. Managing Poorly Drained Pasture Land

Pastures on poorly drained soils are usually thrifty because fine soil and plant food from higher land usually have been deposited there

by rains. The plants, if well adapted, are usually productive. Unless the desired plants are growing in these areas they should be sown. If the land is permanently wet, reed canary grass may be useful. Alsike and Ladino clover and redtop, creeping bent, and rough-stalked meadow grass make good growth in moist to wet soils.

Wet spots and swamplands serve a useful purpose as such. Water-fowl and other water animals, such as beaver and muskrat in their habitats, may add more to the country's net income than may pasturage. Before nature is disturbed materially, areas of more than a few acres deserve examination by soil and drainage experts, wild-life men, and agronomists to determine the best use over the next few centuries. Another point to consider is the relation of upland swamps to water supply. Water supply for wells and streams has been reduced gradually but seriously since this country was settled only a few centuries ago. Water that flows slowly from swamps or percolates into the deep subsoil and later into the bedrock adds to the ground-water supply. Some of it reappears as springs and feeds streams during long periods between rains. Such water serves the farmer for watering livestock; it also supports fish and other water life in streams.

Farm ponds might easily be built in some of these wet areas for watering livestock and for fish production. In some ponds, either wild or tame ducks might be grown. For fish alone, under conditions that can be made favorable, there is little doubt but that some wet areas might produce far more food as fish ponds than as pastures.

If it is decided to pasture such an area, inexpenive open drains may well be established to remove the surplus water from the surface. Doing this permits the soil to settle, warm up, and produce grasses for feed earlier than when too wet. Take off worthless trees and brush as time permits, and remove competition and give the grass all the sunlight available. Grasses that grow in shade or even partial shade are low in feeding value and make only a small yield.

5. Treating Muck-land Pastures

Surface drainage for the removal of water is beneficial, and cutting off brush and trees, as suggested in the preceding paragraph, is desirable. If the pasture fails to make good growth a year or two after draining, fertilization may be needed. Muck lands are often low in potash for vegetables and feed crops. On some mucks

potash is needed for good growth of clovers and grasses. In the absence of experimental information, a trial may be made. Put 200 pounds of muriate of potash an acre on permanently staked strips 2 rods wide and at least 30 or 40 rods long. If the muck area contains but a few acres, such treatment may well extend across it to find any changes in the soil. At the edges enough mineral soil may have been washed in to supply the needed potash and other minerals. An occasional muck-land area is low in phosphorus. If the potash fails to improve the growth of grass and clover (which may have to be seeded), try using 400 or 500 pounds of superphosphate on 2-rod strips that overlap one-half of the potash-treated strips. In this way a general idea is gained as to whether the pasture needs potash alone, phosphorus alone, or both on the whole area. It may even be that neither potash nor phosphorus is beneficial without other treatment. Consult the county agricultural agent or the state extension agronomists. Similar problems may already have been solved in the general area. Cut off sedges and coarse grass in late summer to improve the feeding value of the herbage.

6. Burning Pastures in the Spring

Burning pastures in the South has long been practiced to produce fresh spring growth. The purpose of burning is to destroy the unpalatable and nearly undigestible dead vegetation that remains from the previous year's growth. Fresh, palatable, nutritious new growth, without any admixture of old wire grass, comes on. Cattle relish this fresh growth and make good gains on it, but they make slow gains on the old mature grass. Burning early while the soil is moist to reduce the destruction of soil organic matter is desirable. Burning of pastures should always be done under control. The burning of woods, however, is not recommended; if done it should be in accordance with the directions of foresters.

In Kansas, grazing tests of burned and unburned pastures for the period of the experiment did not show definitely detrimental results from burning. Burning sometimes decreases the number of weeds in pastures, but it also increases the proportion of the less valuable species of forage plants.

7. Grazing Pasture Lands

Details of grazing management are not to be discussed in this volume. That is outside its province. There is no one type of

grazing management that fits all the pasture-plant mixtures. Some plants require close grazing; others will not endure it. Grazing, therefore, must be adapted to the pasture plants, the livestock, and the seasonal growth of the plants (see Fig. 173).

Wild white clover is the outstanding pasture plant that requires close grazing of the grasses that grow with it. Kentucky and Canada bluegrasses and bent grasses endure close grazing and can, therefore, be grown to advantage with wild white clover.

A serious difficulty with the bluegrasses, particularly Kentucky and rough-stalked meadow grass, is that they become practically

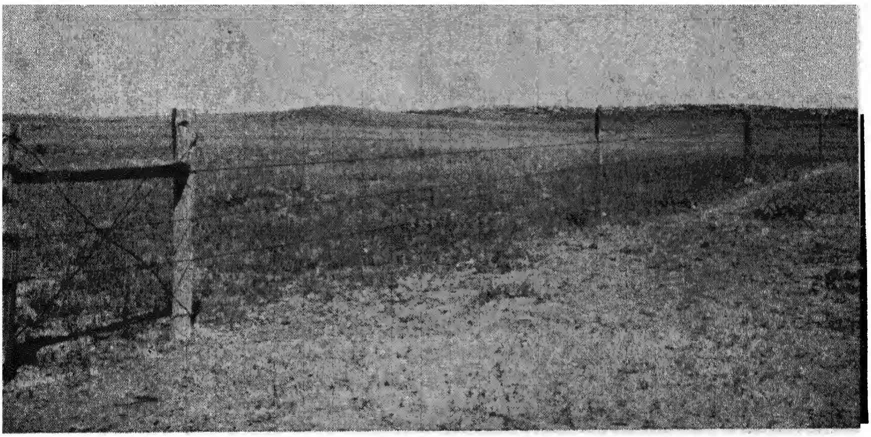


FIG. 173. Overgrazed pasture in Wyoming. Grazing too closely under conditions that are not very favorable for grasses may permanently injure the stand. In areas of low rainfall severe grazing may lead to wind erosion, and under heavy rains, to erosion. (*Soil Conservation Service, U.S. Department of Agriculture.*)

dormant in the hot part of the growing season. On bluegrass pastures, therefore, that were close-grazed immediately before the hot season, there is nothing for livestock to eat during hot weather. Other pasturage must be provided to carry the stock through that period. The stems of Canada bluegrass do remain green late into the fall and, presumably, continue to be palatable and nutritious.

The giant white or Ladino clover, on the other hand, is soon killed out by close grazing. It needs from 4 to 6 inches of growth and may be expected to stay in pastures from 3 to 5 years or somewhat longer under very favorable conditions of soil and competition.

Alfalfa and smooth brome, timothy, crested wheat grass, and other grasses do not stand close grazing. Hot-weather grasses and legumes are essential for all-season grazing in the humid part of the country.

Alfalfa grows best in hot weather and, with smooth brome, fits this category. Timothy recovers slowly after it is grazed down or cut for hay. To get good results from biennial white sweet clover, it must be grazed as closely as possible to defer seeding and complete maturity of the plant. After that, of course, it makes no further growth and supplies no feed.

Annual lespedezas have come into wide use in a belt with Missouri (Fig. 174) and Arkansas on the west, eastward across Kentucky and Tennessee to North Carolina and Virginia on the east. Exceptional use is made of them in Missouri by means of the 1-year wheat-

FIG. 174. Two-year-old beef steers on lespedeza pasture in Missouri. Lespedeza and grass produce good growth of beef cattle in the area to which lespedeza is well adapted. (*James E. Comfort, University of Missouri.*)

lespedeza rotation. Once established, lespedeza seeds so profusely that it covers the soil at every opportunity. In wheat it germinates in the spring, and in 3 weeks after the wheat is harvested lespedeza is ready for grazing. Plenty of seed for maintaining the crop is produced even during fairly close grazing. The land is plowed in late summer, wheat is sown, and the cycle is repeated. Lespedeza, thus used, supplies supplemental grazing for permanent pastures at a time when the latter are most likely to be producing almost nothing.

Millets and Sudan grass along with aftermath of alfalfa, red, or Ladino clover meadows may be grazed during the hot period of slow growth by the regular pasture crops.

SUMMARY

1. Pastures, which occupy about one-half of the land in farms in the United States, produce our cheapest feed. These pastures vary greatly in the quantity of grazing they furnish. Some pastures feed a cow, or other

animal unit, to the acre throughout the grazing season; others require up to 10 acres and even more to feed one animal unit.

2. Pastures on farms are of three kinds; unplowable, permanent pastures; plowable, permanent pastures; and rotation pastures.

3. On unplowable pastures, mow the brush and weeds to give pasture plants a chance. Use lime, phosphorus, potash, and manure as needed.

4. If the sward is thin, seed an adapted pasture mixture after stirring the soil to improve the catch.

5. On plowable pastures with a poor stand of good pasture plants, plowing often is the best way to reestablish a good stand of the most desirable pasture plants. Fertilizing, liming, and manuring are needed the same as on unplowable pastures. One difference is that the lime, phosphorus, and potash can be mixed with the soil. This usually gives better results than top-dressing alone.

6. Permanent pastures that have a good stand of the better pasture plants may be improved by surface application of lime and fertilizers. Lime, in particular, however, gives better results if it is mixed with the soil than if it is applied on the surface.

7. In the establishment of new long-term pastures, liberal applications of lime, if legumes require it, and phosphorus are essential. If the land is known to be deficient in potash, mix it also with the soil. Later, however, surface dressings of potash may be used to advantage.

8. Use a good, well-adapted seeding mixture. Even if it is expensive, it is economical in the long run.

9. Use caution in the application of much nitrogen on pastures that have a good stand of legumes.

10. Use inexpensive surface drains to remove some of the excess water from poorly drained pasture areas. Usually mowing brush and weeds, and other needed management practices rather than fertilization are sufficient to obtain satisfactory production.

11. Similar treatment may be all that is needed on muck-land pastures. Many muck-land pastures, however, are low in potash, and a surface dressing of muriate of potash is needed every other year.

12. Controlled burning of pastures destroys the worthless, dead grass of the previous season and encourages the growth of fresh, nutritious grass.

13. Control the grazing. Do not turn stock out on pasture in the spring until the soil has settled and growth is well under way and the weather is warm enough for sustained production. In the fall, remove the stock early enough to get several inches of growth before winter comes. Pasture plants need to store food in their roots for use in early growth the following spring.

14. In the bluegrass areas, supplemental crops are needed in midsummer to provide all-season grazing.

14. Managing Garden, Fruit, and Lawn Soils

ALTHOUGH the management and fertilization of soils in general have been considered in Chaps. 1 to 12 inclusive, further application of the principles is made under the following activity headings in this chapter:

1. Managing Garden Soils
2. Fertilizing Vegetable Crops and Flowers
3. Managing and Fertilizing Fruit Soils
4. Managing and Fertilizing Lawn Soils

1. Managing Garden Soils

Good management of the garden is important because considerable outlay for tools, seed, fertilizer, manure, and spray or dusting materials and a lot of hard work go into it. Satisfying results can be achieved only by doing the right thing straight through from the selection of the soil until the crops are harvested.

Selecting Well-drained Soils. Always select well-drained soil for the garden, for the lawn, and for the production of fruits and flowers. In this connection, the reader is advised to reread the sections on The significance of Color of Subsoils and Hardpan and Drainage in Chap. 1. Well-drained soils are more easily managed in every way than slow-draining ones. Moreover, they can be planted earlier and worked sooner after rains, but, of course, soils that drain quickly are droughty in long periods of low rainfall. With well-drained soils there is less loss of time after rains than with slow-draining ones. And this is a matter of consequence with commerical gardeners, florists, and fruit growers. Provide for irrigation of all these types of crops in humid as well as in drier areas. It is essential in order to keep production fairly uniform over the seasons.

Applying Manure. All garden crops respond to manure, and manure produces many beneficial effects on soils (Chap 8). Well-

rotted manure is preferred for vegetables, flowers, and lawns. For one thing, most of the weed seeds have been killed while the manure was rotting. None, or few, therefore, will be put on the garden soil. This is important because it is difficult to control weeds among tiny vegetable plants. Moreover, the plant food in rotted manure is already available to crops when it is put on. Fresh manure must first decay and there may be some delay before plants can use the plant food. Make liberal applications of manure for gardens; it

FIG. 175. Rye seeded among vegetables. In the latitude of New York, rye sown during the first half of September in a season of normal distribution of rainfall may be expected to produce a cover like this. The rye was sown on September 15. The sweet-corn stalks have been cut to give the rye more sunshine. Winter cover is essential on sloping land.

helps in the production of vegetables and in maintaining the organic content of the soil. Plenty of organic matter produces good tilth or conditions that are favorable for plant growth. Much heavier rates of application are common for gardens than for field crops. Twenty or 30 tons, or even more, to the acre are often used on gardens and for vegetable crops.

Using Green-manure Crops. It is good practice to seed rye, oats, wheat, or barley in gardens and on many vegetables late in the growing season (Figs. 175–176). Some plants of the green-manure or cover crop will not be killed by the harvesting operations. Or early-harvested vegetables may be followed by a seeding of one of these grains. Use any of the grains, but rye is usually cheapest and

makes most growth in late fall and early the following spring. Whatever growth of grain is made protects the soil over winter and takes up plant food that might otherwise be lost in drainage from the soil. Such plant food then becomes available to crops when the green material decays in the soil. None of these grains should be allowed to head out before they are plowed under. If the spring is dry, plow the green crop down at least 3 weeks before planting. One reason for this is that a growing green-manure crop takes so much water

FIG. 176. Oats sown among vegetables. Even among cabbage and kale a seeding of oats or rye makes good growth. Corn stalks were cut and strewn between the rows. Rye, however, in most places is better than oats.

from the soil that it may become too dry to plow or overly dry for the vegetable crop that is to follow.

Applying Part of Fertilizer before Plowing. Recent experimental work shows the advisibility of getting part of the fertilizer well into the soil. About half of the fertilizer for the home vegetable garden may well be scattered by hand on the surface of the soil, which is then plowed. Plow soon after fertilization so that rain does not dissolve and carry away any of the more soluble part of the fertilizer. By plowing under some time ahead of planting vegetables, some distribution of fertilizer takes place throughout a zone near the bottom

of the furrow. So placed, fertilizer should encourage deeper development of crop roots than when all of the fertilizer is put on the surface. In wet seasons plant roots tend to grow near the surface. If a dry period comes later in the season the roots are unable to follow the moisture downward. As a result the crop suffers. With deeper placement of fertilizer, at least somewhat deeper root development should follow. When dry weather comes the crop is in a better position to obtain the water it needs for growth and for keeping alive. Higher yields, therefore, should result from the plowing down of one-half of the year's fertilizer application.

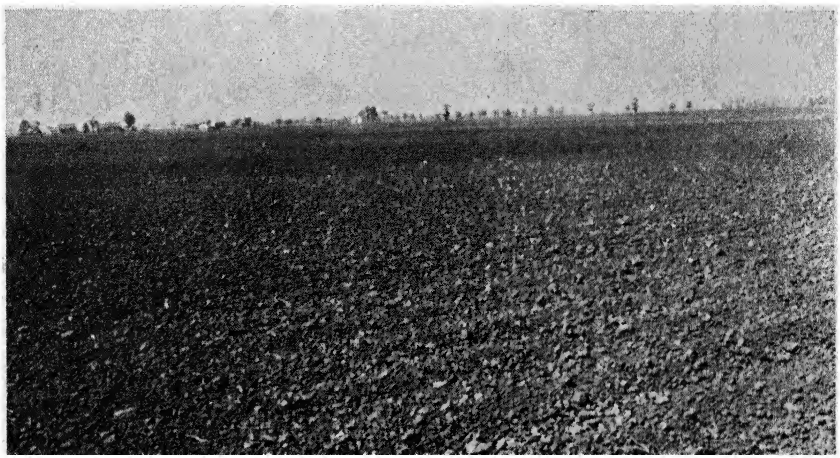


FIG. 177. A good seedbed on a loamy soil. This possesses all the qualities of a good seedbed for garden crops. An important one is that it be weed-free, as this soil is.

Plowing the Soil Early in the Spring or the Preceding Fall. Early plowing is good practice because it permits the soil to become firm by settling and as a result of rains. A good seedbed, it may be recalled, is one that is firm underneath and that has a mellow surface. The lower half of the plowed soil should be firm but not hard or compact. If a heavy rain falls on plowed soil of medium to fine texture that is already wet, it may settle to a compact condition. This is too hard for garden vegetables. Disking, spring-tooth harrowing, or other stirring to loosen most of the plowed soil is essential for good vegetable production. The depth of plowing mentioned, or about 6 to 8 inches, is suitable for most garden crops. In some parts of the country, particularly those with heavy soils, fall plowing is helpful. Freezing and thawing produce desirable granulation. If

the soil is not well drained or if it is subject to blowing, plow the garden in the spring.

FIG. 178. A heavy soil that was made too fine. This heavy silt loam was cultivated too fine and rolled down just before a heavy rain. A very hard crust on the surface was the result. Small-seeded crops failed to come up through it. The surface had to be stirred again before seeding.

FIG. 179. A coarser seedbed on a heavy soil. This soil is the same as shown in Fig. 178 and is less than 20 feet from the same spot. This area was left much rougher and lumpier than the other and the crust formed was not so thick and hard. Less work was needed to prepare a suitable seedbed for small-seeded crops on this area than on that shown in Fig. 178.

Making a Good Seedbed. A good seedbed is fine on sandy soils, but on heavy silt loams and heavier soils a very fine surface is undesirable (Figs. 177, 178, and 179). A fine, heavy soil is badly puddled and crusted over by heavy rains. Especially is this true if a heavy

rain falls on soil that is already wet. The crust may become so hard that many crops fail to get up through it. Squash and beans, especially limas, have great difficulty pushing their way through a thick, hard crust. In fact, many seedlings fail and die in the attempt. A poor stand results with a poor yield as the consequence unless there is still time to replant the crop. A few lumps 2 or 3 inches in diameter are not objectionable. Such lumps do not melt down completely

FIG. 180. Small garden tractor cultivating vegetables. The cultivating attachment is in use. This type of outfit is suitable for the small commercial garden or for the large home garden of fruits and vegetables. (*Bolens Products Co.*)

and form a crust except in a prolonged heavy rain. The steel garden rake makes a seedbed that is entirely too fine and one that is subject to severe crust-formation.[1] For tiny-seeded crops a narrow row can

[1] For more than a quarter of a century I have had a kitchen vegetable garden on a silty, clay loam soil. Although I own a steel garden rake I never use it to make a fine-surfaced seedbed. Very early I found that crusting was far worse in finely divided than in somewhat lumpy soil. On this kind of soil I cultivate to break up the crust after every heavy rain and at other times enough to hold the weeds under perfect control. It is not difficult if one pulls or hoes them out while they are small. I plant corn among the small clods but cover the seed with fine soil and pack it slightly under normal moisture conditions. Sometimes, but not often, corn has some difficulty in getting up if planted a little too deeply.

be freed of lumps and seeded. They come up under favorable conditions and later the lumps soften so that cultivation can be given them in a wholly satisfactory way.

Controlling Weeds While They Are Young. It is easier to control weeds while they are tiny than after they have attained considerable size. Simply scraping them off at the surface kills them while they are tiny. In a small garden use a hoe with a blade at one side and two prongs or fingers on the other. Such a tool has proved excellent for all purposes. In fact, this hoe and a spading

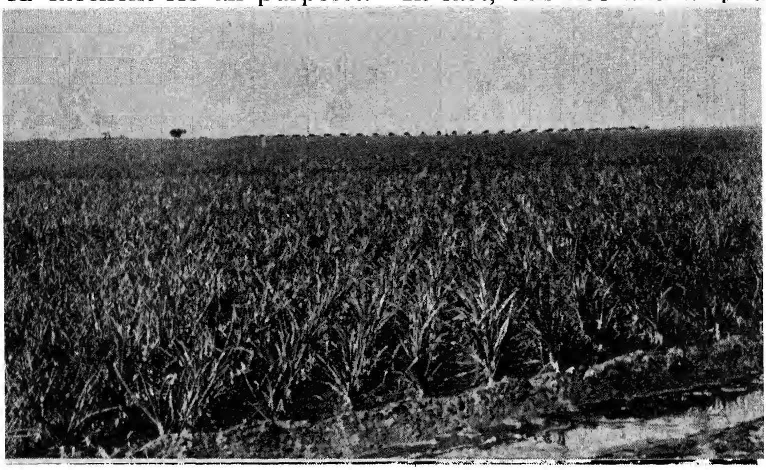


FIG. 181. Irrigating onions in Texas. Closely planted onions with ample water supplied by irrigation in addition to rainfall produce large yields. (*S. H. Yarnell, Texas Agricultural Experiment Station.*)

fork are about all the tools needed for a garden of a size to be spaded. For a larger garden, a wheel hoe or power cultivator (Fig. 180) is a great aid in getting the hoeing done at the right time and without too much labor. Any crust that forms after heavy rains needs to be broken up in order that aeration of the soil may take place satisfactorily. Seeds must have oxygen from the air in order to germinate, and plant roots also require oxygen for growth. Crops on heavy soils, therefore, are helped by cultivation in addition to the benefit from controlling weeds (Figs. 181 and 182). See Killing Weeds with Oil, page 74.

Covering Soil with Paper. Some years ago a black tarpaper was sold for covering the soil to prevent weed growth and to hold moisture. It served both purposes. In fact, one might cover the soil between rows of crops with this paper, go away for a month's

vacation, and come back to a garden in perfect condition. In the absence of this black paper, cardboard-carton material or newspaper of 8 or 10 thicknesses serves the same purpose. In fact, these materials let rainwater into the soil even better than does the tarpaper. On gently sloping land the paper is laid in the opposite way from shingles to take in water, not shed it. A mulch of straw, hay, or weeds serves in the same way around tomato plants and in addition the mulch keeps the fruits clean. In a wet season it is nearly impossible to have enough mulch to protect the tomatoes from such insects as wireworms and slugs. They do much damage on heavy soils with excessive rainfall unless a thick mulch is used.

FIG. 182. Picking snap beans on a large operation in the Everglades, Florida. More than 100 workers may be seen in this view. (*R. V. Allison, Florida Agricultural Experiment Station.*)

Rotating Vegetable Crops. Because of insect infestation or infection by plant disease it is desirable to rotate vegetables. To do this a record must be kept of the location of each crop. Probably this is not feasible for the small garden, but it is practicable in larger ones. Rotation in the vegetable garden is of no aid in controlling insects such as European corn borer or Mexican bean beetle that migrate from place to place. It is with soil-borne diseases such as clubroot of the cole crops (cabbage family) and wilt of cucumber that rotation may aid in control. In addition many of the arguments used in Chap. 12 apply to vegetable crops as well as to field crops.

2. Fertilizing Vegetable Crops and Flowers

The problem of fertilizing vegetables and flowers is so broad that complete details cannot be given. The general picture, however, may be outlined.

Testing the Soil. A test of the soil for lime requirement is a first step. Some vegetables and flowers are sensitive to acidity and some of them require high acidity for best growth. The liming problem, therefore, is not so simple as might at first appear. Potatoes require a fair degree of acidity for the control of potato scab, but if the acidity becomes too strong, potato yields are cut down badly. The growing of potatoes free from bugs, blight, and scab is a professional job. In fact, potatoes are not now regarded as a good crop for the amateur gardener to grow.

Many old gardens have been limed or have had wood or coal ashes or both dumped on them for more than a century. Such gardens test alkaline and are the right place to grow cabbage, cauliflower, kale, Chinese cabbage, Brussells sprouts, turnips, spinach, carrots, beets, peas, beans, and broccoli, but not potatoes. Many old gardens have been overlimed to a condition that is detrimental to many crops. In general, slight acidity is preferable to alkalinity. One should lime gardens and flower beds only in accordance with crop needs as indicated by tests for acidity and lime requirement.

Fertilizing Liberally. One-half of the fertilizer has already been plowed under. Put the remainder on along rows of vegetables and about transplanted crops, such as tomatoes and cabbage. Annual flowers may be similarly treated. Instructions for the use of fertilizers and lime are usually given on the basis of the acre. For the benefit of gardeners with small areas, quantities of lime and fertilizer

TABLE 32. EQUIVALENT QUANTITIES OF FERTILIZER AND LIME FOR DIFFERENT-SIZED AREAS, IN POUNDS

For an acre	For 1,000 square feet	For 100 square feet	For 100 feet of row 16 inches apart
100	2.50	0 25*	0 33
200	5.00	0 50	0.66
300	7.50	0.75	1.00
500	12 50	1.25	1.66
800	20 00	2.00	2.66
1,000	25 00	2 50	3.33
1,500	37 50	3 75	5 00
2,000	50 00	5.00	6 60
2,500	62 50	6 25	8 26
3,000	75 00	7 25	10 00

* To avoid using small fractions of a pound, 40,000 square feet instead of 43,560 was considered to be the area of an acre for this calculation. These are approximate weights for the fertilization of lawns and gardens.

per 1,000 and per 100 square feet and per 100 feet of row are given in Table 32.

Using Complete Fertilizer on Gardens. Complete fertilizer, one that has in it all three fertilizer elements—nitrogen, phosphorus, and potash—is usually put on for garden and flower crops. Manure is always desirable but often difficult to obtain in cities and villages in the quantities needed for a small plot of ground. Superphosphate and manure is suitable fertilization for some vegetables. For small areas, dried manures are a desirable substitute for ordinary barnyard manure. Superphosphate or mixed fertilizers may be used to supplement dried manures. The quantities and analysis of fertilizer for vegetables are given in Table 33.

To aid those who work with small plots, the quantities of dried manures that correspond approximately to commonly used rates of farm manures are given in Table 34.

Leafy Vegetables Need Much Nitrogen. Leafy vegetables such as cabbage, spinach, lettuce, cauliflower, broccoli, and kale require a higher proportion of nitrogen in the fertilizer than some vegetables. Corn, snap beans, and lettuce thrive on a fertilizer of the 5–10–5 type. It may be a 6–12–6, 9–18–9, or 10–20–10; the analysis matters little; it is the ratio, twice as much phosphorus as potash and nitrogen, that matters. A fertilizer of this ratio is the best general garden fertilizer. The point is that the leafy vegetables do well with a little more nitrogen than the average garden crop.

Seed Crops Need Much Phosphorus. Here we mean by *seed* crops those that produce ripe seed, such as peppers and tomatoes. Beets, onions, squash, parsnips, and cucumbers also respond to additional phosphorus. The use of superphosphate after midseason may be beneficial, especially in wet years. Phosphorus encourages the maturity of these crops before killing frosts, if they were seeded or transplanted later than average in the season.

Using Phosphorus for Flowers. Flowers bloom not to please the grower but for the purpose of producing seed to perpetuate themselves. Like seed-producing vegetables, therefore, they need plenty of phosphorus on purely theoretical grounds. Here again it is a matter of proportions or ratio between the elements. Plenty of nitrogen and potash are needed to produce good growth, but a liberal supply of phosphorus is needed, too. A 1–3–1 or even a 1–4–1 ratio may be preferable to the 1–2–1 vegetable fertilizer. The 1–3–1 has one-

TABLE 33. FERTILIZATION FOR VEGETABLE CROPS WITH ADDITIONS OF MODERATE QUANTITIES OF ORGANIC MATTER*

Crop	Nutrients to the acre			Ratio	Preferred analyses and application		Minimum approved analyses and application	
	Nitrogen, pounds	Phosphoric acid pounds	Potash, pounds		Analyses	Amount to the acre, pounds	Analyses	Amount to the acre, pounds
For silt loam and clay loam soils								
Asparagus	60–80	140–160	60–80	1–2–1	10–20–10	750	5–10–5	1,500
Brussels sprouts, cauliflower, celery, onions, and early cabbage	60–80	140–160	60–80	1–2–1	10–20–10	750	5–10–5	1,500
Lettuce	40–60	90–120	40–60	1–2–1	10–20–10	500	5–10–5	1,000
Beets, carrots, parsnips, and root crops (12 to 18 inches between rows)	60–80	140–160	60–80	1–2–1	10–20–10	700	5–10–5	1,400
Beets, carrots, and other root crops (24 to 30 inches between rows)	25–35	50–70	25–35	1–2–1	10–20–10	300	5–10–5	600
Snap beans (market)	20–30	60–80	20–30	1–3–1	6–18–6	400	4–12–4	600
Snap beans (canning)	10–15	30–40	10–15	1–3–1	6–18–6	200	4–12–4	300
Field beans	10–15	30–40	10–15	1–3–1	6–18–6	200	4–12–4	300
Cucumbers, squash, pumpkins	20–30	80–120	20–30	1–4–1	5–20–5	500	4–16–4	600
Melons	50–60	80–120	50–60	1–2–1	10–20–10	500	5–10–5	1,000
Domestic and late cabbage	50–60	80–120	50–60	1–2–1	10–20–10	500	5–10–5	1,000
Peas (market) .	10–20	75–100	10–20	1–4–1	5–20–5	400	4–16–4	500
Peas (canning)	10–15	30–50	10–15	1–4–1	5–20–5	200	4–16–4	250
Peppers and eggplant	50–60	80–120	50–60	1–2–1	10–20–10	500	5–10–5	1,000
Potatoes (row application)	50–100	100–200	50–100	1–2–1	10–20–10	600	5–10–5	1,200
Sweet corn (market)	20–30	60–80	20–30	1–3–1	6–18–6	400	4–12–4	600
Sweet corn (canning)	10–15	30–50	10–15	1–4–1	5–20–5	200	4–16–4	250
Tomatoes (market)	40–50	120–140	40–50	1–3–1	6–18–6	700	4–12–4	1,000
Tomatoes (canning)	30–40	110–130	30–40	1–4–1	5–20–5	600	4–16–4	750
Spinach, chard, and other crops grown for greens	40–60	80–120	40–60	1–2–1	10–20–10	500	5–10–5	1,000

For sandy and sandy loam soils

Asparagus	75–100	125–175	125–175	1–2–2	5–10–10	1,500	4–8–8	1,850
Brussels sprouts, cauliflower, celery, onions, and early cabbage	75–125	75–125	75–125	1–1–1	10–10–10	1,000	7–7–7	1,450
Lettuce . .	40–60	75–125	75–125	1–2–2	5–10–10	1,000	4–8–8	1,250
Beets, carrots, parsnips, and root crops (12 to 18 inches between rows)	75–100	125–175	125–175	1–2–2	5–10–10	1,500	4–8–8	1,850
Beets, carrots, and other root crops (24 to 30 inches between rows)	35–50	50–100	50–100	1–2–2	5–10–10	750	4–8–8	950
Snap beans (market)	25–35	50–75	50–75	1–2–2	5–10–10	600	4–8–8	750
Snap beans (canning)	10–20	25–40	25–40	1–2–2	5–10–10	300	4–8–8	400
Field beans	10–20	25–40	25–40	1–2–2	5–10–10	300	4–8–8	400
Cucumbers, squash, pumpkins	35–50	50–100	50–100	1–2–2	5–10–10	750	4–8–8	950
Melons.	40–60	75–125	75–125	1–2–2	5–10–10	1,000	4–8–8	1,250
Domestic and late cabbage	35–50	50–100	50–100	1–2–2	5–10–10	750	4–8–8	950
Peas (market)	30–40	50–75	50–75	1–2–2	5–10–10	600	4–8–8	750
Peas (canning)	10–20	25–40	25–40	1–2–2	5–10–10	300	4–8–8	400
Peppers and eggplant	40–60	75–125	75–125	1–2–2	5–10–10	1,000	4–8–8	1,250
Potatoes (row application)	60–80	125–175	125–175	1–2–2	5–10–10	1,500	4–8–6	1,850
Sweet corn (market)	35–50	50–100	50–100	1–2–2	5–10–10	750	4–8–8	950
Sweet corn (canning)	15–25	30–50	30–50	1–2–2	5–10–10	400	4–8–8	500
Tomatoes (market)	40–60	75–125	75–125	1–2–2	5–10–10	1,000	4–8–8	1,250
Tomatoes (canning)	40–60	75–125	75–125	1–2–2	5–10–10	1,000	4–8–8	1,250
Spinach, chard and other crops grown for greens	50–100	50–100	50–100	1–1–1	10–10–10	750	7–7–7	1,050

* Fertilizer Recommendations for New York, *Cornell Extension Bulletin* 281, pp 18–19, 1939

Manure When more than 10 tons of manure is used on the land the year the vegetable crop is grown, a ratio higher in phosphoric acid than that suggested is used In place of a 1–3–1 ratio for tomatoes on silt loam, with more than 10 tons of manure use a 1–4–1 ratio, such as a 5–20–5, 600 pounds to the acre In place of a 1–2–2 ratio for cucumbers on sandy soils, a 2–4–3 ratio, such as a 6–12–9 analysis, could be used at the rate of 600 pounds to the acre, or a 1–4–2 ratio, such as a 4–16–8 analysis at the rate of 500 pounds to the acre.

Band applications The recommendations given in the table (except for potatoes) are based on broadcast applications Experimental evidence indicates that when fertilizer is applied in bands near the row, the rate of application may be reduced It is dangerous to apply fertilizer directly in the row, especially with peas and beans

Side dressings Crops planted on sandy soils are likely to give a profitable response to a side dressing of 100 to 200 pounds to the acre of nitrate of soda, sulfate of ammonia, or a comparable quantity of nitrogen from some other readily available carrier. Crops on heavier soils should receive a side dressing of nitrogen whenever growth is slow

TABLE 34. QUANTITIES OF DRIED SHEEP, POULTRY, AND COW MANURES THAT SUPPLY THE SAME AMOUNT OF NITROGEN AS "AVERAGE" FARM MANURE*

Tons of average manure to the acre	Dried sheep manure		Dried poultry manure		Dried cow manure	
	Pounds	Tons	Pounds	Tons	Pounds	Tons
8	3,200	1.6	1,777	0.88	6,000	3.00
10	4,000	2.0	2,222	1.22	7,462	3.73
12	4,800	2.4	2,666	1.33	9,000	4.50
15	6,000	3.0	3,333	1.67	11,200	5.60
20	8,000	4.0	4,444	2.22	15,000	7.50
25	10,000	5.0	5,555	2.78	18,600	9.30
30	12,000	6.0	6,666	3.33	22,400	11.20

NOTE For 1,000 square feet use 1/10 of these amounts, for 100 square feet use 1/100 of these amounts, for 75 feet of row 16 inches apart use 1/100 of these amounts

* These equivalents are figured on the basis of the nitrogen in them On the basis of either the phosphorus or potash the amounts of dried manures would be different

half more phosphorus than, and the 1–4–1 ratio has twice as much phosphorus in 100 pounds of fertilizer as does the 1–2–1 ratio. This is on the assumption that all of them contain the same percentage of nitrogen, perhaps 5 per cent. The rather rank-growing flowers respond to some manure early in the season.

For such acid-loving plants as azalea, laurel, and rhododendron, acid soils are required. If the soil is too slightly acid or has a pH of much above 5.5, the soil may be removed from small areas and replaced with a natural soil of the desired acidity. If the area is too large or there is no near-by, convenient source of acid soil, the original soil may be acidified. Acidifying requires attention, including testing the soil for pH several times during the growing season. The quantity of treatment to use to acidify soils is given in Table 14, Chap. 6.

3. Managing and Fertilizing Fruit Soils

Fruit crops, in comparison with vegetables and most field crops, are relatively permanent crops. They occupy the land from several years to 50 or 100 years. The cane fruits, such as raspberries and blackberries, occupy the land for 5 or 10 years, peaches an intermediate period, and grapes and apples for long periods. Grapes, of course, can be renewed rather quickly, but the regular-sized apple tree takes a long time to grow to profitable bearing size. Under very favorable conditions trees are still bearing at ages approaching a full century.

Choosing Well-drained Soils. Of course, it is necessary to make certain, first of all, that the climate is suited for commercial production of fruits before proceeding to establish them. Small plantings for home consumption may be risked even without the desired soil and climatic conditions.

Because many fruits occupy the land for a long time, it is essential to select land that is well suited to the particular fruit that is to be grown on a commercial scale. Perfectly well-drained soils are needed for fruits in general. It is true, however, that strawberries and citrus are grown in places where drainage is imperfect. There, strawberries are grown in beds that are raised considerably above the lowest part of the planted area. Special precautions are taken with citrus also. The trees are planted on ridges that are as much as 18 to 24 inches higher than the flat-bottomed drainage ways between the rows of trees. In the North, however, it is seldom that fruit thrives except on well-drained soils and in a climate suited to the particular kind of fruit. An outline of the earmarks of well-drained soils and how to distinguish them from other soils is given in Chap. 1 under Significance of Color in Subsoils and Hardpan and Drainage. Soils that are sufficiently well drained for perfect growth of alfalfa are suited for fruit production. In the heart of a perfect fruit-climate area, something short of perfect drainage might be expected to do fairly well in fruit. Toward the edge of the good fruit-climate area, however, it is best to confine fruits, especially the medium- and long-term ones, to well-adapted soils. Tree fruits require a deep soil for good root development. Much less than 8 feet of soil for tree fruits and about half this depth for bush fruits is not likely to prove satisfactory.

It should be recognized that soils such as deep gravelly loams may be too dry even for such deep-rooted fruit trees as apples. Gravel-fill soils, however, often have a supply of water in the deep substratum that might be pumped from wells for irrigating fruit trees, vines, or bushes.

Plowing and Harrowing Only as Needed. Although apples were formerly clean-cultivated throughout the spring and well into the summer, they are now grown in sod to a large extent. The sod method is a great advantage on steeply sloping land, on land with rock ledges or boulders, and on stony land. Sod has the advantage that it controls erosion by wind or water almost completely. Sod not only conserves the supply of organic matter and nitrogen in the

soil but the grass may add to it. If the grass and legumes or weeds are cut and left on the ground, there is often a gain in both organic matter and nitrogen under the grass. Sod orchards are given considerable applications of nitrogen for apples. Many irrigated Western orchards, however, are clean-cultivated, and cover crops are grown in them.

Peaches, citrus, grapes (Fig. 183), and small fruits are rather generally cultivated. Plowing may well be restricted to a depth somewhat less than for field crops. Shallower plowing permits the development of roots in the lower part of the topsoil which contains

FIG. 183. Grapes on the contour. Rye is the cover crop. It is plowed into the soil before it gets too coarse.

much of the organic matter and the more readily available plant food. This includes that which is applied direct for the fruit and that which is used for the cover crop. Disking may be better than plowing. It mixes trash with surface soil rather than turning it under. Being partly on the surface, the trash protects the soil to some extent from wind and water erosion and helps to hold water against loss by evaporation. Organic matter in the surface encourages absorption of rains by the soil so there will be more water available for the crop.

Growing Protecting Cover Crops. Wherever clean cultivation is given the fruit crop, especially on sloping lands, cover crops are needed to help in the control of erosion (Fig. 184). Most of the crops listed for use as green manures can be used for cover crops (Chap. 10).

Thick seeding as early as other conditions permit is advisable because it produces better protection than does later seeding. Also, a cover crop takes up excess nitrogen and gives fruit better color. Provide lime for the cover crop if and as it may be needed.

If no fertilizer has been used for the previous crop it pays to fertilize the cover crop to get good protection for the soil. Liberal fertilization is advisable, especially if the fruit crop may obtain benefit from it.

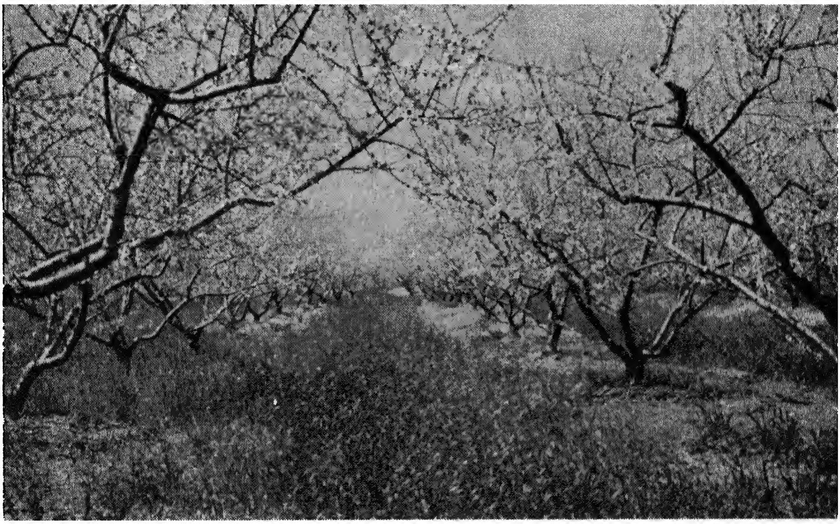


FIG. 184. Peaches on the contour. A rye cover crop between rows of peach trees. Because peaches are usually clean-cultivated, contour planting and the use of cover crops is essential for preventing serious erosion. (*Soil Conservation Service, U.S. Department of Agriculture.*)

Manuring and Fertilizing Fruit Crops. Fruits usually respond to farm manure not only because of the nitrogen in it but also because of the organic matter and probably the minor elements it contains. Sod orchards need liberal fertilization with manure or nitrogen or both. The grasses use much of the nitrogen that is available in the soil, so fruits must be supplied with this element by means of fertilizers. Any of the carriers of nitrogen listed in Chap. 11 will do. Liberal fertilization is desirable, but overfertilization with nitrogen not only delays the maturity of the fruit but makes it soft and of poor flavor, color, and shipping quality.

Small fruits, which usually have grasses growing with them,

respond to fertilization. A complete fertilizer occasionally, with nitrogen every year, may prove helpful. Manure, of course, is good for small fruits as well as for tree fruits. Avoid late application of nitrogen because it retards maturity of the new wood. Wood that goes into the winter immature is likely to winterkill. Winterkilling reduces the quantity of fruiting wood and probably the yield of fruit the following year.

Lime should be used for fruits only if careful tests show that there is need for it or if the cover or interplanted crops need liming.

4. Managing and Fertilizing Lawn Soils

A lawn that was well established requires relatively little attention, other than mowing, for several years. This presupposes that liberal quantities of phosphorus and manure were mixed with the soil before it was seeded.

Although space does not permit of a complete statement on establishing lawns, one point may be stressed. Before making the excavation for a new home, take off and pile separately the original topsoil for producing the final surface of the finished lawn. Bringing in topsoil involves undesirable stripping of the surface soil from another area, perhaps farm land. Also, such soil may bring seeds or roots of weeds that may prove exceedingly difficult to control in the lawn. Quack grass (witch or couch grass) is an example of such a pest in its area of adaptation. Avoid it and other weeds by making certain that they are not present in "imported" soil if you must have it for your lawn. Giving the lawn care and fertilization does help to keep it in good condition. A lawn of pleasing appearance is a source of real satisfaction.

Testing the Soil and Liming, if Needed. Have samples of the lawn soil tested for acidity. If the result of the acidity determination shows slight acidity (around pH 6.0), liming is not necessary. If, however, it is stronger than "moderate" acidity (pH 5.5, Chap. 6, page 169), lime for bluegrass-white-clover lawns. Fifty pounds of finely ground limestone, or about twice as much of coarsely ground stone, to 1,000 square feet will be sufficient for a period of 4 or 5 years. If a bluegrass lawn that is fertilized and well cared for becomes unthrifty without apparent reason, lime it again. Do not lime lawns, however, unless it is reasonably certain that lack of lime in the soil is the cause of its poor condition. Liming is done more for the clover in the lawn than for the bluegrass. Straight bluegrass lawns, except

in areas of strong soil acidity, do not often require liming if they are well fertilized.

Bent Grasses Tolerant of Acidity. Bent grasses are more tolerant of or less sensitive to acidity than are the bluegrasses. In areas of generally strong soil acidity, therefore, it may be wiser to seed the tolerant grasses than to sow the more sensitive ones. If sowing the bent grasses makes liming unnecessary, their use should be encouraged, because after all, testing and liming do take your time and energy from other work. Many people, nevertheless, prefer the bluegrass-white-clover lawn to the bent grasses. They can lime and produce the desired bluegrass lawn.

Producing a Weedless Lawn. Much has been written about the weedless lawn. This was usually a bentgrass lawn that was fertilized with sulphate of ammonia. This nitrogenous fertilizer material (see Table 28, page 285), if used in liberal quantities year after year, makes moderately acid soils more strongly acid. Bent grasses survive, but bluegrasses and white clover and the weeds that grow under similar soil conditions disappear. Other weeds are likely to take their place.

It appears to be better lawn management to use weed killers than to depend on soil acidity to control weeds. The development of weed killers is very rapid at the present time and they hold bright promise for use on lawns and gardens, as well as on a field scale (see pages 73 to 76).

Using Nitrogen or Mixed Fertilizer. For grass lawns that were liberally treated with a source of phosphorus such as superphosphate, rock phosphate, or basic slag at seeding time, nitrogen alone may be all that is needed for some years. Four or five pounds of a carrier of nitrogen, such as nitrate of soda or sulphate of ammonia, to 1,000 square feet, put on before growth begins in the spring, is sufficient. Excessive use of nitrogen makes a rank growth of grass and requires more mowing than is really necessary. After all, what is wanted is a relatively close, thrifty, green cover for the soil.

For older grass lawns, a mixed fertilizer is probably preferable. An analysis fairly high in nitrogen, such as 10–6–4, 8–6–4, or 6–9–4 or 5–10–5, a good garden fertilizer, is suitable. Ten or twelve pounds for 1,000 square feet are all that are needed; or one-half of these quantities of a more concentrated fertilizer like a 10–20–10 is sufficient. Continued use of these mixed fertilizers, in time, may bring in white

clover. If this legume becomes well established and is wanted in the lawn, superphosphate is a desirable fertilizer. Four or five pounds of 20 per cent superphosphate and, on somewhat sandy soils or if clover is unthrifty, 2 pounds of muriate of potash for 1,000 square feet of lawn is advised. Strictly grass lawns, however, must have nitrogen, either in a carrier of nitrogen or in a mixed fertilizer. This type of treatment is suitable also for bent-grass lawns.

Manuring Lawns. Well-rotted manure or dried manure is desirable for lawns. Early spring is a good time to put it on the grass. Moderate rates of application are more desirable than heavy ones because heavy applications produce excessive growth. This requires extra work for mowing. During periods of excessive growth, remove clippings from the lawn. On white-clover lawns, leaving clippings on depresses the clover. A suitable rate of application would be 400 or 500 pounds of well-rotted manure on 1,000 square feet. If the lawn is fertilized every year, fertilizer may be left off the year manure is used. Seventy-five or eighty pounds of dried sheep or goat manure, 50 or 60 pounds of dried poultry manure, or 150 pounds of dried cow manure on 1,000 square feet of lawn are good dressings. Well-fertilized lawns probably need no additional treatment the year dried manure is used.

Watering Lawns. So long as rainfall keeps lawns green and thrifty-looking, watering is not necessary. Excessive watering makes extra work of mowing. If the lawn is to be watered, give it plenty of water to wet the surface soil to a depth of 5 or 6 inches. This requires far more water than is usually put on. Light watering, however, is of little value. It may even be harmful. A little moisture in the top inch of soil encourages the development of roots in that zone. Hot sunny days evaporate this moisture and the grass quits growing and turns brown. Heavy watering or none should be the rule.

Mowing the Lawn. Setting the lawn mower to cut from between 1 and 2 inches is about right on the average, although bent and other creeping grass may be cut a little closer (Figs. 185 and 186). The rate of growth on a lawn varies considerably in different places. Mowing about once a week does much to keep the grass uniform in height and smooth in appearance. During the period of most rapid growth in late spring, however, it is desirable to mow oftener than once a week. The grass grows too tall for the mower to do a clean job of cutting and too much growth is left on the lawn. Such tall growth, particularly

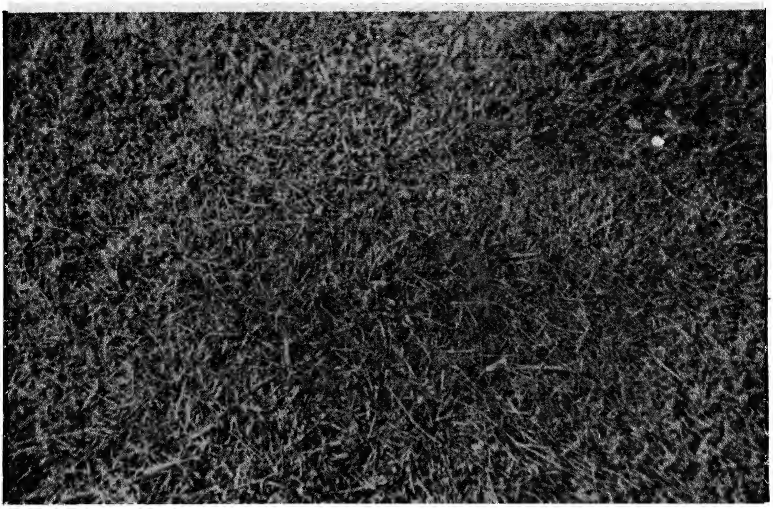


Fig. 185. A good Kentucky bluegrass lawn. This is a typical lawn in the area to which this bluegrass is adapted. This is at a good height for cutting.

Fig. 186. A power lawn mower. Small garden tractors may be equipped with lawn mower as well as with plowing and cultivating attachments. (*Rototiller, Inc.*)

on a bluegrass-clover lawn, is best removed. The clippings contain much nitrogen and it discourages the growth of the clover. The appearance of the lawn is improved by taking off the long clippings. Under conditions of normal growth, clippings an inch or at most two inches long are beneficial to the grasses. Upon decay they supply plant food to the grasses and may help to hold moisture in the soil.

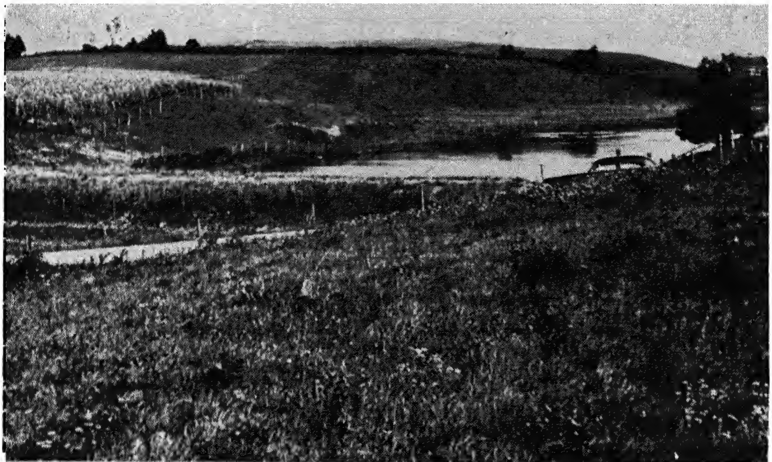


FIG. 187. A valuable farm pond. A pond like this near the buildings may be a suitable source of water for irrigating the garden, the fruit, and the lawn in periods of drought. Irrigation is particularly important for food crops, and for cash and feed crops, too, if the water supply is sufficient. Some communities are organized to control fires, for which purpose a convenient supply of water is essential. Stocking with fish adds to the usefulness of ponds.

In general, except when they are too long, leave clippings on to improve the appearance of the lawn (Fig. 187).

SUMMARY

1. Select well-drained soil for the garden, for fruit, and for house site or lawn. Poorly drained soils are not suitable for these uses.
2. Use fairly good-sized applications of manure on the garden, grow and turn in green manures when possible, and plow the soil early.
3. Control weeds by cultivating while they are small.
4. In gardens of good size, rotate the vegetable crops to help in the control of plant diseases.
5. Fertilize vegetable crops and flowers in accordance with the needs of crops and in accordance with state extension recommendations.
6. Test the soil and use lime only in accordance with the needs of crops—not indiscriminately.
7. Vegetables in general require complete fertilizers. Crops that

produce ripe seed like tomatoes and peppers, and snap beans that are harvested before they ripen, require liberal treatment with phosphorus. Leafy vegetables, such as lettuce, spinach, and celery, require liberal applications of nitrogen.

8. Many flowers respond to fertilization similar to that needed by vegetables in general.

9. Lime for flowers only as soil tests show that lime is needed.

10. Always choose well-drained soil for fruits. They seldom do well on wet soils.

11. After fruits are established, stir the soil only as needed. Apples do well in sod, provided they are given sufficient nitrogen. Pears are productive in sod and should not be treated too liberally with nitrogen.

12. Peaches, grapes, and citrus are usually grown with clean cultivation. There is, however, a tendency to cultivate peach orchards less than formerly.

13. Cultivated fruit lands, especially sloping lands, require cover-crop protection over winter. Winter rye is widely used and winter legumes are useful in the South.

14. Apples and small fruits respond to manuring at moderate rates, such as 8 or 10 tons an acre. Individual apple trees, or apple trees set 40 by 40 feet, may be given 600 to 700 pounds of manure. Spread it under the outer part of the branches for best results. Similar rates of application are suitable for cane fruits.

15. Too heavy fertilization with nitrogen on strawberries tends to produce soft fruit that may rot badly in rainy periods. Peaches respond to moderately liberal treatment with nitrogenous fertilizer.

16. Many lawn grasses tolerate moderate acidity. Lime the lawn only if a soil test shows that lime is needed. Bent grasses are more tolerant of acidity than the bluegrasses. Grow bent grasses, if the soil is a little too acid for bluegrass, rather than lime the lawn. Some weeds are encouraged by liming.

17. In addition to keeping the soil acid to discourage weeds, new weed killers have been developed that are claimed to eliminate weeds without injury to the grass.

18. A good garden fertilizer may be used on lawns as required to keep grasses thrifty. Heavy fertilization produces so much growth as to require frequent mowing.

19. Use weed-free manure in moderate amounts only, because heavy manuring produces excessive growth and requires very frequent mowing.

20. Water heavily enough, when needed, to soak the soil to a depth of 5 or 6 inches. Light sprinkling may produce a shallow root system so that the grass may suffer unduly in dry periods.

21. Mow lawns often enough to keep them neat and uniform in appearance.

15. Keeping Soils Productive over the Years

IN THE Orient, a degree of productivity of soils has been maintained over a period of several thousand years. The older American soils, in contrast, have gone down appreciably in productivity in as short a time as 200 years. Thousands of acres westward from the earliest settlements have suffered losses in crop yields in a single century and even less. Part of the loss in yields has resulted from the use of plant food by crops that have been sold from the farm. Some loss has occurred from natural leaching away in drainage water. More plant food has been lost by washing away over the surface, and by the surface soil itself being washed away. So long as our large reserves of phosphorus and smaller reserves of potash hold out we can restore these nutrients to the soil. The potash reserves, although substantial, are not inexhaustible. When the high-grade deposits are worked out, lower-grade materials will have to be depended upon. Supplies of nitrogen for crops can be maintained indefinitely. Loss of the surface soil, however, lowers the productive power of the land for years to come.

The management and treatment that are needed to keep soils productive over the years are discussed under the following activity headings:

1. Managing the Soil
2. Avoiding Reduced Productivity from Cropping
3. Liming for Legumes
4. Maintaining Active Organic Matter and Nitrogen in the Soil
5. Adding Phosphorus
6. Providing Available Potassium
7. Growing Crops in Suitable Rotations
8. Fertilizing Grain and Forage Crops
9. Fertilizing Cash and Vegetable Crops

1. Managing the Soil

Much erosion has already taken place. Much damage has been done that we cannot undo. Our duty is clear: Hold in place the top soil we now have. In Europe and more in Asia, soil is returned from the valleys or the bottom of slopes to the place from which it came. Such return of soil is not practiced in this country. With further development of earth-moving machinery it is thinkable that the sediment in reservoirs might be returned to the hill lands from which it came. How big a task this is may be visualized if it is realized that 7 inches of topsoil over 1 acre weighs 1,000 tons. With 1-yard outfits this quantity is 1,000 loads; with a 10-yard vehicle it is 100 loads; with 100-ton freight cars it is 10 carloads. If the soil could be moved for 5 cents a ton, the cost is $50 an acre for returning topsoil. For growing feed crops, such cost is prohibitive, but for fruit or vegetable crops, at some future date, such an outlay may be an economic possibility.

Much of this washed-away surface soil was caught in swamps, in pastures and forests, on bottom lands, and in lakes, but much of it went to the ocean. Such soil material cannot be returned to the farms from which it came. The Mississippi Delta is being enlarged over the centuries. The Gulf might be diked out, the land drained, and eventually farmed. When, as, and if reclaimed, this will be highly productive land. Swamps and small lakes may be drained and cultivated after sufficient deposition has taken place. What loss of soil takes place to build up the Mississippi Delta? Consider a depth of 300 fathoms. That is 1,800 feet. The topsoil from twice that number of acres (3,600) must be washed off the productive lands of Illinois, Minnesota, Wisconsin, Iowa, Missouri, Kentucky, Arkansas, Tennessee, Mississippi, and parts of other states to supply the soil for each acre of the Delta.

A thin layer of 12 or 18 inches of true topsoil is sufficient for satisfactory crop production. Although accumulated topsoil to a depth of several feet may be highly productive, greater depths are seldom more productive. Topsoil, in general, is of greatest value to mankind in its original location. It is not good soil management or good public economy to permit the loss of the topsoil from large areas of productive land, even though the topsoil accumulates and builds up small areas of rich land in other places.

Avoid the loss of topsoil by means of some or all of the following practices:

1. Keep up the organic matter in the soil.
2. Plow, prepare seedbed, plant, cultivate, and harvest crops on the contour or across the slopes; not up and down.
3. Crop sloping lands in contour strips with alternate strips always in a soil-protecting crop when the other strip is growing a soil-exposing crop.
4. Terrace the land to take water gently off slopes so it cannot wash away the valuable topsoil.
5. Control or prevent gullying. Following the practices already outlined will largely prevent gullying. Diverting water from gullies, using inexpensive check dams, brush, and vegetation checks the flow of water in gullies and reduces cutting at the same time that some deposition takes place. Grasses, legumes, trees, shrubs, and vines on the sides of gullies complete their control.

We must stabilize the land; must hold it where it is now for the generations that will follow.

2. Avoiding Reduced Productivity from Cropping

Crops are produced in part from plant foods that came out of the soil. When wheat, beans, fruits, and vegetables are sent to market, the plant food in them is lost to the land that produced them. To be sure, the bran of the wheat is fed to animals and the undigested part of it goes back to the soil, but not to *the* soil from which it came. The loss from the soil in a single year is not large, but during centuries the loss becomes very large.

Fortunately, several of the agricultural experiment stations in this country have studied this problem for nearly three-quarters of a century. Of course, no one piece of work has been in progress for that length of time. Illinois, Pennsylvania, Ohio, and Missouri for long periods and New Jersey, South Dakota, Iowa, and other states for shorter periods have been at work on this and other soil and crops problems. The work in Illinois is credited with being the oldest continuous soil and crops experiment in this country.

The work on the Morrow plots at Urbana, Illinois, was started by George E. Morrow in 1876 (Fig. 188). Records of yields have

been kept since 1888. More extensive work was begun there in 1902 and 1903 by Eugene Davenport and Cyril G. Hopkins. The work in Pennsylvania was begun by W. H. Jordan in 1881. That in Ohio was initiated at Wooster by Charles E. Thorne in 1893 and that in Missouri by J. W. Sanborn shortly afterward.

In the Illinois work the yield of shelled corn was 50.6 bushels as an average for the years 1888, 1889, and 1890 on this productive, brown,

FIG. 188. The Morrow plots at Urbana, Illinois. The corn back of this information board is the sixty-sixth to be grown in this experiment. What has happened to yields may be seen in Fig. 189. Photographed by the writer at the Illinois Agricultural Experimental Station in 1941.

prairie silt loam. The yield on the same untreated plots 44 years later was 22 bushels of shelled corn. The loss in yield was 60 per cent or three-fifths.

During the years that produced corn in the rotation of corn and oats, the yield after 44 years was 28 bushels of corn. The corn in the rotation of corn, oats, and clover at the end of these 44 years produced 41.8 bushels. It is notable that there was a loss in yield of corn in every comparison, but it was less in the rotations than for continuous corn.

In 44 years

Continuous corn lost	28.6 bushels to the acre
Corn in corn-and-oats rotation lost............	22.6 bushels to the acre
Corn in corn—oats—clover rotation lost	9 0 bushels to the acre

In 1903 the plots were divided and since then moderate quantities of manure, limestone, and rock phosphate have been put on one-half of each of the original plots. During the 34 years following 1904 the treatment increased the yields as follows:

Continuous corn from 22 to 45.5 bushels to the acre..	Increase 23 5 bushels an acre
Corn in corn-and-oats rotation from 28 to 52.6 bushels to the acre	Increase 24 6 bushels an acre
Corn in corn—oats—clover rotation from 41.8 to 66.1 bushels to the acre	Increase 24 3 bushels an acre

The treatment was applied directly for corn. It is not surprising, therefore, that the increase in yield of corn was practically the same on the land continuously in corn as in corn alternated with oats, and as in a rotation of corn, oats, and clover.

The loss in yield without treatment is what stands out in this work.

The results of the experimental work in Ohio were reported by Thorne[1] in 1924 (Fig. 190). Yields are reported by 4-year averages. Comparison is made between the first and the last 4 years in a total period of 30 years. Without treatment these crops, grown continuously for 30 years, lost in yield as follows:

Corn, from 29.1 bushels to 15.4 bushels	Loss 13.7 bushels an acre
Oats, from 26.9 bushels to 13.9 bushels.. ...	Loss 13 bushels an acre
Wheat, from 10.6 bushels to 5.2 bushels. .	Loss 5.4 bushels an acre

These losses in yield for continuous corn, oats, and wheat were one-half for a 30-year period. The use of nitrogen, phosphorus, and potassium slowed down the losses of all three crops.

Corn, oats, wheat, clover, and timothy were grown in a 5-year rotation. One year of a leguminous crop in a 5-year rotation could not be expected to reduce markedly the down trend in yields of these crops. It is notable that the yield of each crop but wheat went down even in rotation without treatment. With manure alone, there was an increase in the yield of every crop except corn, which had a small loss in yield. The application of nitrogen, phosphorus, and potassium, even in moderate amounts, markedly improved the yield of all the crops in the rotation. And these yields were much higher than

[1] THORNE, C. E., The Maintenance of Soil Fertility, *Ohio Agricultural Experiment Station Bulletin* 381, pp. 300–315, 1924.

for the same treatments when corn, oats, and wheat were grown continuously.

On the basis of the long-term work in Illinois and Ohio, the following conclusions are reached:

1. Grain yields drop rapidly if they are grown continuously without manure or fertilizer over a period of 30 to 50 years.

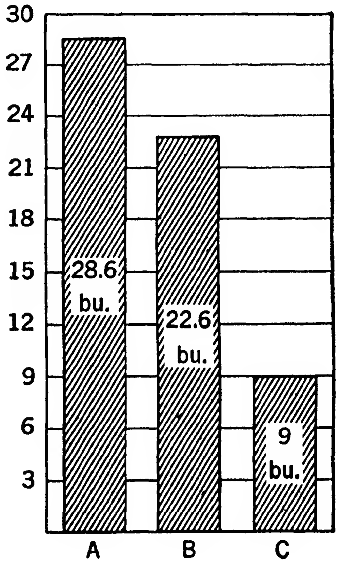


Fig. 189.

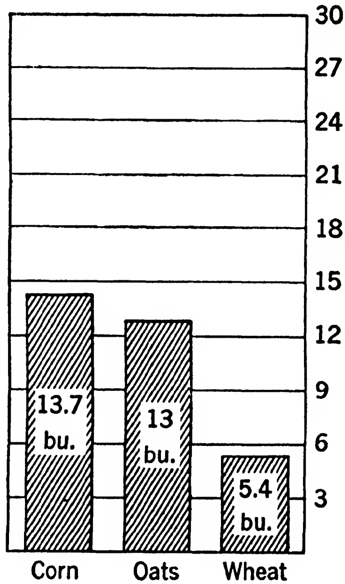


Fig. 190.

Fig. 189. Reduction in yield of corn in 44 years at the Illinois Agricultural Experiment Station. *A*, corn grown every year; *B*, corn alternated with oats; and *C*, corn rotated with oats and clover.

The loss in yield of corn in rotation was only one-third as much as the loss in yield of corn grown every year. No fertilizer used to produce these yields.

Fig. 190. Comparative losses in yield of corn, oats, and wheat grown continuously for 30 years at the Ohio Agricultural Experiment Station.

2. Alternating corn and oats in a 2-year rotation lowered the loss in yield of corn.

3. Corn in the corn—oats—clover rotation suffered only a slight loss (9 bushels an acre) in yield in a period of 44 years.

4. Fertilizing the soil with manure, rock phosphate, and limestone doubled the yield of continuous corn.

5. This fertilization restored the yield of corn in the corn-oats rotation to that of 44 years earlier.

6. In the rotation of corn, oats, and clover, the fertilization increased the yield not only to the original but to one-third above the yield of corn in 1888.

This experimental work shows definitely that fertilization and rotation can restore yields to those of 40 years earlier, and can easily increase them profitably above the earlier yields. The use of lime, manure, and phosphorus is much more productive if crops are grown in rotation than if grown continuously. To be effective, the rotation, however, must contain a biennial or a perennial legume like red clover or alfalfa.

3. Liming for Legumes

Liming for legumes is essential if they are to make good growth and add liberal quantities of nitrogen to the soil for the use of other crops in the rotation. The best way to know how much lime is needed to the acre for legumes is to test carefully selected samples of the soil (Chap. 6, page 178) for lime requirement. Once sufficient lime for clover has been used, a ton of finely ground or correspondingly more of coarsely ground limestone to the acre is usually enough for clover the next time it is grown, if this is within 5 or 6 years. This is on the assumption that it is not more than 5 years since the previous application of lime was made. Liming not only corrects soil acidity, but supplies the legume crop and others in the rotation with an abundance of calcium and magnesium for use as nutrients.

4. Maintaining Active Organic Matter and Nitrogen in the Soil

Keeping up the supply of fresh or active organic matter in the soil is not easy, but without it crops cannot thrive for any long period. It is not well to add large quantities of organic matter at any one time. The losses will be great if that is done. Putting back into the soil moderate quantities of organic matter and doing it often is the best way of keeping up the supply of this valuable material. If a large part of this organic matter consists of leguminous crops, they will add some nitrogen to the soil for the benefit of the other crops in the rotation. The details of keeping up the organic matter and nitrogen content of the soil are covered in Chap. 8.

5. Adding Phosphorus

Most of the humid-region soils of this country were relatively low in phosphorus when they were brought into cultivation. Many of them have suffered losses of phosphorus during these years of cropping. Manures and organic matter seldom add; they merely return phosphorus to the soil. Moreover, both are low in phosphorus. There is no way to replace phosphorus except to buy it and put it on the soil. Yields of crops, rather generally, are increased by additions of phosphorus.

The long-term experimental work in Ohio and Illinois and a mass of experimental evidence in other states all show the beneficial effects of phosphorus on the yields of crops. The grains and leguminous crops, particularly, are benefited. Liberal use of phosphorus is profitable in the long-term maintenance of the productivity of our humid-region soils.

6. Providing Available Potassium

Many American humid-region soils contain large supplies of total potassium in the upper 3 feet of the soil. The heavier loams, silt loams, clay loams, and clays contain large quantities of potassium. The lighter soils, such as the sandy and gravelly loams and loamy sands, however, are low in total potassium. Glaciated soils are high in potash. Some of them have as much as 50,000 pounds to the acre in the topsoil. Many older soils are not so well supplied with this essential plant-food element.

Manure supplies—or returns—potash to the soil. A 10-ton coat of manure furnishes about 100 pounds of potash, and this quantity is a large share of that needed for good yields of a 4-year rotation of feed crops. Crop residues and the soil also supply potassium to crops. Nevertheless, the use of potash in fertilizer often pays well.

Coarse-textured mineral soils, especially if unmanured, do not furnish crops with enough potash for even fair-sized yields. Except for these coarse soils it is not lack of potash but low availability of potash for crops that limits crop yields. If manuring and plowing in organic matter do not supply and liberate enough potash for crops, this fertilizer element can be added. Either of two ways can be followed. Potash may be put on the soil as muriate of potash, or it may be put on in a mixed fertilizer. If large quantities are needed as for

alfalfa (200 to 400 pounds to the acre), it is least expensive to put it on as muriate of potash or other straight fertilizer salt.

7. Growing Crops in Suitable Rotations

The benefits of growing crops in suitable rotations were discussed in Chap. 12. The improvement in crop yields and the benefit to the soil can hardly be sufficiently stressed. The long-term work in Ohio and Illinois emphasizes the effects of rotating crops on the yield of corn in the heart of the corn-growing region of the country. From the standpoint of maintaining yields and keeping up organic matter and nitrogen in the soil, the leguminous crop is the most important one in the whole rotation. A second year of a legume or legume-grass mixture is needed in a rotation that has 2 grain crops in it. Rotating crops—including leguminous crops—is one of the first essentials in the broad program for keeping up the productivity of the soil over the years.

8. Fertilizing Grain and Forage Crops

Nitrogen, phosphoric acid, and potash must be provided in relatively inexpensive form for grain and forage crops. Wheat stands more of cash outlay than the feed grains because it brings more cash directly. Making conditions favorable for legumes and growing them is a first step in the fertilization of these crops. Some of the legume goes back into the soil the year it is seeded, as does also the aftermath, unless it is pastured off. Even then a considerable part of it stays on the soil as manure. The manure that is made in feeding the leguminous hay should go back into the soil with the least possible loss by leaching and rotting. Wherever feasible, use leguminous green-manure crops to help keep up the supply of nitrogen for grains and grasses and other crops.

The manure directly and organic matter indirectly help to supply the available potash these crops need. If there is still a deficiency, potash in mixed fertilizers or muriate of potash may be used. The cost of purchased potash is a point to be kept in mind, yet if the soil is markedly deficient in potash, put it on; it usually pays well.

Because humid-region soils are low in phosphorus, it must be bought and added to the soil. The quantity to use to the acre for feed-grain, pasture, and hay crops varies somewhat with the expected returns. Thirty pounds of actual phosphoric acid to 1 acre a year on

the average for the rotation increases the yield materially. This amount of phosphoric acid is supplied in 150 pounds of 20 per cent superphosphate or 200 pounds of the 16 per cent analysis. It would be supplied in the same respective amounts of 5–20–5 or 4–16–4 fertilizers.

If basic slag is the source of phosphorus, a somewhat larger quantity of phosphoric acid is recommended. Slag, it should be remembered, is a particularly good form of phosphorus for acid-soil pastures and meadows.

Where finely ground rock phosphate is used, from ½ to 1 ton to the acre once during the rotation gives good results with clover, alfalfa, and other legumes and the grain crops that follow.

The increase in the nutritional value of feed crops for livestock and of food crops for man from the use of an abundance of lime and phosphorus on the soil deserves more attention than it has yet received. From the standpoint of crop yields alone, however, liberal use of phosphorus is profitable.

9. Fertilizing Cash and Vegetable Crops

It is no less important for vegetables than for feed crops that leguminous material and other organic matter be turned under for cash and vegetable crops. More fertilizer than is generally put on for these crops will pay beyond question under present price conditions. Fertilizers are low priced compared with vegetables and other crops.

Many low-analysis fertilizers are used throughout the heavy fertilizer-using area in the East and Southeast. Fertilizers that contain fewer than 18 units of plant food certainly are less economical to purchase and use than those that have 24 to 30 units and more of plant food.

High-analysis and concentrated fertilizers in liberal quantities to the acre are recommended for cash crops and vegetables. There is a large investment in land, labor, seed, plants, and other expenses for the production of these crops. Failure to use ample plant food might lead to loss where liberal fertilization ought to yield a profit.

SUMMARY

1. Manage the soil to control erosion because that is the one most important step in keeping soils productive over the years.

2. Avoid lowered productivity from continuous growing of soil-depleting

crops such as cotton, corn, tobacco, vegetables, sweet and grain sorghums, and the grains—wheat, oats, rye, and barley.

3. Lime as much as is needed to grow thrifty, inoculated legumes that fix large quantities of nitrogen and leave much organic matter in the soil.

4. Keep up the active organic matter in the soil by putting on manure, returning leftovers from crops, and growing and turning down green-manure and cover crops as they fit into the rotation.

5. Use phosphorus liberally to produce large, profitable yields. Most American soils were originally deficient in phosphorus; therefore, it must be applied for best results on many soils.

6. Use potash on sandy and gravelly soils wherever the increased yields pay well for it.

7. Many silt-loam soils also respond to applications of potash.

8. Grow crops in suitable rotations that contain leguminous hay crops that grow 2 years or more. Avoid too large a proportion of clean-cultivated crops, particularly on sloping lands and on soils of low productivity.

9. Fertilize grain and forage crops moderately but enough to produce good, profitable yields. Along with manure and the production of legumes on the hay and pasture lands, phosphorus is often sufficient.

10. Cash and vegetable crops usually produce good yields and, therefore, returns that warrant liberal use of complete fertilizers in addition to farm manure and turning in green manures.

11. Fertilizing, as outlined here, builds up a supply of plant food in the soil that will be of great value over the coming years.

Appendix I
Chemical Information for Study of Soils, Fertilizers, and Crops[1]

Many practical soil, lime, and fertilizer problems involve a knowledge of chemistry, which treats of the constitution of substances and changes in their composition. Such knowledge will richly repay the practical student of soils and crops since the use of chemistry simplifies many explanations. Some of this essential information is presented in the paragraphs that follow.

Essentials of Chemistry

First let us consider a common substance that is very important in the study of soils. This substance is the gas, carbon dioxide. It is breathed out by all living animals, and results from the burning of coal, wood, and other organic materials, and from the decay of organic matter of all kinds. Both atmospheric air and the air in the soil contain carbon dioxide. All higher plants use carbon dioxide in their growth. They are, therefore, directly dependent on carbon dioxide. Hence all animals are indirectly dependent on it and these in turn produce it.

Carbon dioxide is composed of carbon and oxygen. Everyone is familiar with carbon in the form of charcoal, and this element is an important constituent of coal, sugar, and all plant materials. Oxygen is a gas that makes up nearly one-fifth of the air we breathe. It is oxygen that supports the burning of substances by fire. The proportions of carbon and oxygen in carbon dioxide are always the same. By weight there are 12 units of carbon and 32 units of oxygen, or in simpler terms 3 parts of carbon and 8 parts of oxygen.

Carbon dioxide dissolves in, or combines with, water and forms carbonic acid. These facts concerning carbon dioxide illustrate the make-up of a simple compound and a simple chemical reaction. Moreover, this acid had much to do with the breakdown of rocks and the release of substances that are used for food by plants.

Elements. It has been stated that carbon dioxide is made up of carbon and oxygen. Carbon, oxygen, and nitrogen, which make up about four-

[1] Dr. H. O. Buckman read this section and made helpful suggestions.

fifths of the air, together with iron, copper, silver, and many other substances are called *elements*. In the ordinary sense elements are not broken up into smaller units. Many common substances are not elements but are chemical combinations of two, three, or more elements.

Compounds. These chemical combinations of elements are called *compounds*. Compounds are not merely mixtures of elements; they are chemically united. Take carbon dioxide; it is composed of the solid, carbon, and the gas, oxygen. The compound is quite unlike either of these elements. The air we breathe, in contrast, is mainly a mixture of oxygen and nitrogen. If oxygen and nitrogen are chemically combined, one of the oxides of nitrogen results. This is wholly unfit for breathing by animals. Many elements, in fact most elements, occur in nature as compounds and usually can be separated into their constituent elements only with some difficulty.

Thus far 96 elements have been found, but only about one-fifth of that number need be considered in our study of lime, fertilizers, soils, and plants.

Symbols. Symbols are used in the same way and for the same purpose as abbreviations. Pa. is used as the abbreviation for Pennsylvania, so C is used for carbon, O for oxygen, and N for nitrogen. With these elements the initial letter of the English name is the symbol. Because C had already been used for carbon, something else had to be used for such elements as calcium and copper. For calcium the initial and the second letter, Ca, are used. For copper the symbol is Cu. For potassium (Kalium in Latin) the initial letter, K, is used. For iron (Ferrium in Latin) and sodium (Natrium in Latin) the initial and the second letter are used. Fe and Na, then, are the symbols for iron and sodium.

As already stated, most of the elements in soils and crops occur in the form of compounds. In fact, only a small proportion of the substances in and on the earth is naturally in the form of elements. The rest are in the form of numberless compounds. The elements of greatest importance in the study of soils and crops are given in Table 1, page 5.

The Make-up of Matter

Elements, such as copper and iron, cannot be simplified, but they can be reduced to particles of minute size. The very smallest quantity of an element that can exist as such is infinitely small in size and is known as the *atom*. Atoms can be broken down (otherwise the atomic bomb would not have been possible), yet they act as the unit in the reactions with which we are mainly concerned in studies of soils and crops.

Certain atoms possess strong chemical attraction, or affinity, for certain other atoms. Under favorable conditions such atoms combine to produce *molecules*. A molecule, therefore, is the smallest portion of a substance that has the chemical properties of that substance. In compounds the simplest

molecule consists of 2 atoms of different kinds. The molecules of some substances contain many atoms, and sometimes many kinds of atoms. In elements, 2 or more identical atoms may constitute a molecule.

From what has been said, it is clear that both atoms and molecules are very small and countless numbers of them are present even in minute quantities of substances. At ordinary temperatures atoms and molecules are in motion and consequently have considerable energy.

Using Symbols to Show the Make-up of Matter

The symbols listed in Table 1 stand for the elements but do not indicate how much of the elements are present or are under consideration. Symbols, however, may be used for atoms and molecules, and then they stand for definite quantities of elements or compounds. Thus, symbols show the make-up of substances. The symbols that together represent the make-up of a compound are called a *formula*. Water is a compound and its make-up is shown by its formula HOH, commonly written, H_2O. This formula shows how many atoms and what elements make up the molecule of water. The small figure 2, called a subscript, after H shows that 2 atoms of hydrogen together with 1 atom of oxygen form the compound, water. Four molecules of water are represented by the expression $4H_2O$. Thus written, the number 4 applies to all that follows it. The expression $4H_2O$ then represents 8 atoms of hydrogen and 4 atoms of oxygen.

In gases the molecules of elements consist of 2 atoms. The elements, oxygen, nitrogen, chlorine, and hydrogen may, therefore, be represented respectively by O_2, N_2, Cl_2, and H_2. The expression $3N_2$ then means that 3 molecules, each of which consists of 2 atoms of nitrogen, are under consideration.

Carbon dioxide, which has been mentioned, is represented by the formula CO_2. One atom of carbon is combined with 2 atoms of oxygen to form the compound CO_2. Following are the formulas for a few common substances: pure high-calcium limestone, $CaCO_3$; muriatic or hydrochloric acid used by tinsmiths, HCl; and rust of iron, (ferric oxide) Fe_2O_3. Each formula shows the make-up of one molecule of each of these substances.

Using Symbols to Write Chemical Reactions

Wood, straw, grass, and coal are made up largely of hydrogen, H, oxygen, O, and carbon, C. In the burning of these substances carbon combines with oxygen from the air and forms carbon dioxide, CO_2. The reaction is as follows: $C + O_2 \rightarrow CO_2$. Two atoms of oxygen combine with 1 atom of carbon and form 1 molecule of carbon dioxide. This reaction shows one of the main occurrences during the burning of these highly carbonaceous materials. In any fire, however small, millions of molecules of carbon dioxide are formed.

The burning of these materials, in which oxygen is combined with carbon, is called oxidation. In the process heat is liberated. We take advantage of the heat given off in oxidation to warm our homes in winter and to cook our food. For those purposes we burn coal, wood, oil, or gas, but in each the process is the same. Carbon is oxidized to carbon dioxide and heat results. In the soil, organic matter is oxidized by soil organisms. They give off carbon dioxide and the organic matter is said to be oxidized or to undergo decay or rotting.

In the soil some of the carbon dioxide that is produced in the decay of manures and crop residues dissolves in or combines with water in the soil. This reaction may be written in shorthand, as it were, thus:

$$CO_2 + H_2O \rightarrow H_2CO_3$$

H_2CO_3 is called carbonic acid. A molecule of CO_2 combines with a molecule of H_2O to form 1 molecule of carbonic acid. That this is an acid can readily be demonstrated by means of any test for acid. Any acid that dissolves in water turns blue litmus paper pink, and this is exactly what occurs when blue litmus paper is brought into contact with carbonic acid. In soils that are well supplied with organic matter, enormous quantities of CO_2 are produced, and this is one reason why soils tend to become acid. Moreover, this acid aids in making plant foods from the mineral part of soils available to plants. It should be understood, of course, that these reactions are extremely simple in comparison with many of the chemical reactions that take place in soils during the growth of plants.

Acids and Bases

Acids and their chemical opposite, bases, are of vital importance in a study of the elements of chemistry and of soils and fertilizers as well. Because acids and bases occur in soils and fertilizers and in crop plants, an understanding of them is essential for the student of soils and crops.

Acids. Muriatic, or hydrochloric, acid is widely used in chemical work. Because of its simplicity it is useful in explaining differences in the make-up and action of acids. The formula for hydrochloric acid is HCl. It is evident from its formula that a molecule of hydrochloric acid is composed of 1 atom of hydrogen, H, and 1 of chlorine, Cl. Hydrochloric acid dissolves readily in water. In a water solution some of these atoms wander away from each other, or are said to be "dissociated." The resulting parts are called *ions* and the process of separation is termed *ionization.*

By ionization, hydrochloric acid furnishes hydrogen which is extremely active. Only acids (and acid salts) supply hydrogen in this way. The sour taste of vinegar (acetic acid) is representative of the taste of weak acids. The

sour taste is imparted by the hydrogen ions which are present in all acids. That hydrogen is common to acids is seen in the following list.

Name	Formula	Positive ion	Negative ion
Hydrochloric acid.	HCl	H	Cl (chloride ion)
Carbonic acid.	H_2CO_3	H	HCO_3 (carbonate ion)
Nitric acid	HNO_3	H	NO_3 (nitrate ion)
Sulphuric acid.	H_2SO_4	H	SO_4 (sulphate ion)

Upon the dissociation of an acid, its hydrogen ions take on a positive charge of electricity and are called positive ions. In contrast, the other part of the acid takes on a negative charge and becomes negative ions. In all the acids we will deal with, except hydrochloric acid, the negative part consists of two or more elements and is called a *radical*. It is important that the names of the negative ions be understood and learned. In simple reactions, the carbonate radical acts as a unit. The carbon travels arm in arm, as it were, with the 3 oxygen atoms; they do not wander away from each other. If they separate they are no longer a carbonate radical.

An acid is a compound that in water dissociates into hydrogen ions (positive) and negative ions. Acids in water solution have a sour taste that is imparted to the mixture by hydrogen ions. Acids react readily with many substances, particularly metals, and show an acid reaction with indicators, of which blue litmus turning to pink is representative. Indicators are of great service in dealing with acids. A thorough understanding of acids is essential to an understanding of bases.

Bases. All acids contain hydrogen and all bases contain the OH group. In this group, oxygen and hydrogen are held together so tightly that they act as a unit. It is called the *hydroxyl*, or the *basic* radical, and the hydroxide ion has a negative electrical charge.

Because of its negative charge of electricity the OH radical readily combines with such common elements as calcium, sodium, and potassium. In a dissociated condition, these elements, like ionic hydrogen, are positively charged. The resulting compound is a *base*. Four bases may be listed for further consideration.

Name	Formula	Negative ion	Positive ion
Potassium hydroxide . .	KOH	OH	K (potassium)
Sodium hydroxide.	NaOH	OH	Na (sodium)
Ammonium hydroxide.	NH_4OH	OH	NH_4 (ammonium)
Calcium hydroxide	$Ca(OH)_2$	OH	Ca (calcium)

It may be noted that the OH (hydroxide) radical is present in all of these compounds; the only difference between these bases is in the positive ion. The name of the positive ions plus the hydroxide gives the complete name of these bases. Become familiar with them as soon as possible.

In addition to the OH radical, bases contain a metal or an element or radical that functions like a metal. Nitrogen and hydrogen become closely associated in the ammonium ion, take on a positive electric charge, and combine with the negative hydroxide to form ammonium hydroxide. Ammonium then acts exactly the same as a metal in forming this base. Ammonium hydroxide (sometimes called spirits of hartshorn, or household ammonia) is of great agricultural importance in the change of nitrogen in farm manure and other organic matter in the soil to forms that plants can use in their growth.

In summary, a base, or hydroxide, is a compound of a metal, or a substance that acts like metal, and one or more OH radicals. In water, bases dissociate into the positive metallic ions and the negative OH ions which are decidedly active. A water solution of bases has a soapy feel and a sharp taste from the OH ion. A basic solution turns litmus paper blue, and this effect on litmus shows that the solution is *alkaline*. A comparison of the properties of acids and bases should help to fix in mind the differences between them. The same litmus paper that turned blue in a basic solution changes to pink in an acid one. Litmus, therefore, can be used to determine whether in a given solution you have a base or an acid.

Neutralizing Acids and Bases. Acids and bases are antagonistic and in solution tend to neutralize each other. In any mixture of acids and bases, the one that is present in excess completely neutralizes the other. Should they be present in exactly the same molecular strength they neutralize each other precisely and the solution becomes neutral; that is, it is neither acid nor alkaline.

Consider what takes place when two elements, with which we are concerned in fertilizers, are brought together as an acid and a base. KOH is potassium hydroxide and HCl is muriatic or hydrochloric acid. In water solution the following reaction takes place:

$$\underset{\text{Hydrochloric acid}}{HCl} + \underset{\text{potassium hydroxide}}{KOH} \rightarrow \underset{\text{potassium chloride}}{KCl} \text{ and } \underset{\text{water.}^1}{HOH}$$

In a chemical reaction like this, 1 molecule of acid neutralizes 1 molecule of base. One molecule of salt (KCl) and 1 of water are the products of the reaction. The acid, HCl, has completely and precisely neutralized the base, KOH. Similarly any acid and any base or alkali may react with each other and form 1 molecule of a new substance, called a *salt*. If a small excess of

[1] Commonly written H_2O.

hydrochloric acid is used, the final mixture is acid because of a dominance of hydrogen ions. In contrast, if an excess of potassium hydroxide is used, the solution becomes alkaline, or basic, because of the presence of an excess of OH ions. In the chemical laboratory many uses are made of a knowledge of this neutralization process.

Valence. It may have been noted that 1 atom of some elements unites with 1 atom of another element and that 1 atom of some elements unites with 2 or even 3 or more atoms of other elements. Of those already discussed, 1 K atom unites with 1 OH, 1 Cl or 1 NO_3 to form KOH, KCl, or KNO_3. In contrast, 1 Ca, unites with 2 OH groups, or 2 Cl atoms to produce $Ca(OH)_2$ or $CaCl_2$. The capacity of atoms to unite with other atoms is called *valence*. Stated another way, valence is the power of elements to combine to form molecules of compounds. Potassium, 1 atom of which combines with 1 atom of Cl, is called *mono*valent. Calcium, 1 atom of which unites with 2 Cl atoms or 2 OH groups, is said to be *di*valent (di means 2). Aluminum, Al, a common element in the mineral part of soils, combines with 3 Cl, 3 NO_3 or 3 OH to form $AlCl_3$, $Al(NO_3)_3$, and $Al(OH)_3$. Aluminum, therefore, is trivalent (tri = 3).

H, the positive ion of acids, is monovalent. It combines with the OH ion to form water, HOH or H_2O. Since H is monovalent, OH also must be monovalent because they combine completely with each other. With this information and the formula for an acid or a base it is easy to determine the valence of the negatively charged element or radical in acids and of the positively charged element or radical in bases. You must know the valence of elements and radicals if you are to write and balance chemical equations accurately.

Salts. It has been shown that if such a simple but active acid as HCl is brought into contact in solution with a simple but active base such as KOH, the two combine by means of a rearrangement of the components. This chemical reaction occurs:

$$\begin{array}{ccccccccc} HCl & + & KOH & \rightarrow & KCl & + & HOH & (H_2O) \\ \text{acid} & + & \text{base} & \rightarrow & \text{salt} & + & \text{water} & \end{array}$$

It should be noted that every atom of each element on the left of the arrow must be accounted for on the right. There is no loss of matter in chemical reactions. If the exact combining weights of both HCl and KOH are used, they precisely neutralize each other to form the *salt*, KCl, and water, HOH. The H ion is split off from the acid and the OH ion from the base; in the solution they, because of their great chemical affinity for each other, combine to form HOH, or water. A *salt* is a compound that is formed when the hydrogen, H, of an acid is displaced by a metal (or substance that acts like a metal).

Potassium salts are of great importance in fertilizers. Special attention, therefore, may be given them.

Acid	Formula	Base	Salt	Formula
Hydrochloric	HCl	$+KOH$	= potassium chloride	$KCl + HOH$
Nitric	HNO_3	$+KOH$	= potassium nitrate	$KNO_3 + HOH$
Sulphuric	H_2SO_4	$+2KOH$	= potassium sulphate	$K_2SO_4 + 2HOH$
Carbonic	H_2CO_3	$+2KOH$	= potassium carbonate	$K_2CO_3 + 2HOH$

It may be well to note that the chlorine and nitrate radicals are monovalent and that the sulphate and carbonate radicals are divalent. Memorize the valence of every element and radical as you proceed.

These acids plus $NaOH$ give salts as follows:

HCl – $NaCl$ sodium chloride + HOH
HNO_3 – $NaNO_3$ sodium nitrate + HOH
H_2SO_4 – Na_2SO_4 sodium sulphate + $2HOH$
H_2CO_3 – Na_2CO_3 sodium carbonate + $2HOH$

The same acids plus NH_4OH give salts:

HCl – NH_4Cl, ammonium chloride + HOH
HNO_3 – NH_4NO_3 ammonium nitrate + HOH
H_2SO_4 – $(NH_4)_2SO_4$ ammonium sulphate + $2HOH$
H_2CO_3 – $(NH_4)_2CO_3$ ammonium carbonate + $2HOH$

These acids plus $Ca(OH)_2$ give salts:

$2HCl$ – $CaCl_2$ calcium chloride + $2HOH$
$2HNO_3$ – $Ca(NO_3)_2$ calcium nitrate + $2HOH$
H_2SO_4 – $CaSO_4$ calcium sulphate + $2HOH$
H_2CO_3 – $CaCO_3$ calcium carbonate + $2HOH$

These formulas show the valence of these elements and radicals. Sodium, potassium, and ammonium all have a valence of 1 and replace 1 H atom. Because calcium, Ca, displaces 2 H atoms or combines with 2 Cl atoms, both of which are monovalent, calcium is divalent. Moreover, calcium combines directly with the divalent radicals SO_4 and CO_3.

It is of interest to note that all of the potassium salts are carriers of fertilizer potassium. Sodium nitrate and ammonium chloride, ammonium nitrate, and ammonium sulphate, and calcium nitrate are common carriers of fertilizer nitrogen. Calcium carbonate is the active part of limestone that is used for liming acid soils. A knowledge of valence and of how these common fertilizer salts are formed from acids and bases will be of real service in gaining an understanding of soils and fertilizers.

Appendix II
Approximate Equivalents and Formulas

Weights

1 ounce (avoirdupois)	= 28.4 grams
1 gram	= 0 0353 ounce (avoirdupois)
1 pound (avoirdupois)	= 454 grams
1 kilogram	= 2.2 pounds (avoirdupois)
1 gallon	= 231 cubic inches
1 gallon of water	= 8.346 pounds (avoirdupois)
1 cubic foot of water (7.48 gallons)	= 62.42 pounds[1] (avoirdupois)
1 liter (dry measure)	= 0.9082 quart
1 quart	= 1.1011 liters

1 inch of water over 1 square foot weighs 5 2 pounds.
1 acre-inch of water weighs 226,512 pounds, or 113¼ tons.

Linear Measure

1 inch	= 2 54 centimeters
1 meter	= 39.4 inches, 3.28 feet
1 mile	= 5,280 feet or 1,609.35 meters
1 kilometer	= 1,000 meters or 3,281 feet or .6214 mile

Square Measure

1 square foot	= 144 square inches
1 acre	= 43,560 square feet or 160 square rods
1 square mile	= 1 section or 640 acres
1 acre	= 4,047 square meters or .4047 hectare
1 hectare	= 10,000 square meters or 2.471 acres

Cubic Measure

1 cubic inch	= 16.4 cubic centimeters
1 cubic foot	= 1,728 cubic inches
1 bushel (US)	= 2,150.42 cubic inches

Temperature

Temperature, Centigrade degrees = (temperature, Fahrenheit degrees − 32) × $\frac{5}{9}$
Temperature, Fahrenheit degrees = (temperature, Centigrade degrees × $\frac{9}{5}$) + 32

Formulas

Circumference of circle	= diameter × 3.1416
Area of circle	= radius squared × 3.1416
Area of sphere	= 4 × radius squared × 3.1416
Volume of sphere	= (diameter cubed × 3.1416) ÷ 6
Volume of cylinder	= area of base × height

[1] 62.43 pounds at 4°C., 62.5 pounds often used in practical calculations.

Appendix III

Locations of State Agricultural Colleges, Extension Services, and Experiment Stations

State	Post Office
Alabama	Auburn
Alaska	College
Arizona	Tucson
Arkansas	Fayetteville
California	Berkeley
Colorado	Fort Collins
Connecticut Storrs Station	Storrs
Experiment Station	New Haven
Delaware	Newark
Florida	Gainesville
Georgia Experiment Station	Athens
Hawaii	Honolulu
Idaho	Moscow
Illinois	Urbana
Indiana (Purdue University)	Lafayette
Iowa	Ames
Kansas	Manhattan
Kentucky	Lexington
Louisiana	University
Maine	Orono
Maryland	College Park
Massachusetts	Amherst
Michigan	East Lansing
Minnesota	St. Paul
Mississippi	State College
Missouri	Columbia
Montana	Bozeman

Nebraska	Lincoln
Nevada	Reno
New Hampshire	Durham
New Jersey (Rutgers University)	New Brunswick
New Mexico	State College
New York (Cornell)	Ithaca
State Experiment Station	Geneva
North Carolina	Raleigh
North Dakota	Fargo
Ohio	Columbus
Experiment Station	Wooster
Oklahoma	Stillwater
Oregon	Corvallis
Pennsylvania	State College
Puerto Rico Federal Station	Mayaguez
College Station	Rio Piedras
Rhode Island	Kingston
South Carolina	Clemson
South Dakota	Brookings
Tennessee	Knoxville
Texas	College Station
Utah	Logan
Vermont	Burlington
Virginia	Blacksburg
Washington	Pullman
West Virginia	Morgantown
Wisconsin	Madison
Wyoming	Laramie

United States Department of Agriculture . . . Washington, D.C.

Appendix IV
Definitions of Terms Used

Absorption. The taking in of water by soil much as a sponge, towel, or blotter does. Plants are said to absorb plant food or nutrients; they take these solids through a living membrane, which is different from the action of a towel.

Acid. A substance in which H ions dominate the OH ions is acid. An acid soil, therefore, is one in which the H ion is dominant.

Adsorption. The action of a body in holding a gas on its surface, such as charcoal, or fine soil particles or organic matter taking on and holding water vapor or gases.

Aggregate. A group of soil particles (usually dominated by fine- and medium-sized particles); a crumb or granule.

Aggregation. The bringing and holding of small individual soil particles together in crumbs, granules, or aggregates.

Alkali Soil. One that contains alkali salts, usually including sodium carbonate, in harmful quantities. Specifically defined as being of pH 8.5 or higher alkalinity. Essentially "black" alkali soils. See Saline Soil.

Alkaline Soil. One whose pH is above 7.0 or 7.3. See Saline soil.

Alluvial Soil. A soil formed from the deposits rather recently made by streams, usually first-bottom or flood-plain material, subject to overflow.

Ammonia. A compound of nitrogen and hydrogen, NH_3.

Ammonification. The production of ammonia or its compounds, usually by soil organisms.

Arid Climate. See Climate.

Base. A compound that is capable of uniting with an acid so as to neutralize it and form a salt.

Base Map. A map that shows such political subdivisions as state, county, township lines, roads, streams, and other features that might be helpful for a specific purpose such as mapping soils.

Bedrock. The country rock under the soil and subsoil.

Black Alkali. See Alkali Soil.

Bog Soil. A soil developed in a swamp from water-loving vegetation; therefore, usually high in organic matter.

Buffer. A substance that resists sudden change in pH, toward either stronger acidity or alkalinity.

Burning. Destruction of organic matter on soils by fire. Also, the injury to seeds or plants from too high a concentration of fertilizer or spray or dusting material for control of insects or disease.

Calcareous Soil. One that is alkaline because of the presence of free calcium or magnesium carbonate or both.

Calcium Carbonate. Limestone is composed largely of calcium carbonate, $CaCO_3$.

Calcium Hydroxide. This product is formed by the addition of water to burned lime. It is water-slaked lime, $Ca(OH)_2$.

Calcium Oxide. Calcium oxide is produced by burning limestone at high temperatures. Carbon dioxide, CO_2, is driven off and calcium oxide, CaO, remains.

Capillary Capacity. The largest quantity of water a soil can hold; any addition of water causes drainage.

Capillary Water. The water that is held in soils by surface-tension forces between and around soil particles.

Carbon. One of the elements required for growth by all plants. Charcoal is fairly pure carbon.

Carbon-nitrogen Ratio. The relationship between the weight of carbon and that of nitrogen in soils and plant materials. Pounds or percentage of carbon divided by pounds or percentage of nitrogen gives the number of pounds or percentage of carbon for each pound or percentage of nitrogen.

Carrier. Fertilizer materials are spoken of as carriers. Superphosphate, rock phosphate, and bones are called carriers of phosphorus. Similarly, muriate and sulphate of potash and kainite are said to be carriers of potassium.

Cash Crop. One grown to be sold for cash in contrast to crops that are grown for feed. Cotton, tobacco, peanuts, cabbage, and others are called cash crops.

Catch Crop. One seeded between or in regular crops to catch and hold nutrients and incidentally afford protection and perhaps supply readily decaying organic matter.

Class (Soil). See Soil Class.

Climate.

Arid. The rainfall is low and ineffective in producing more than a sparse vegetative cover. In cool climates about 10 inches and less, although 15 or 20 inches of water may be no more effective in the warmer climates. Distribution over the year also influences effectiveness. Ten inches favorably distributed in northern climates is sufficient for dry farming.

Humid. A region in which rainfall (plus snow) is sufficient for ordinary production of crops without irrigation. Here, too, the effectiveness of water is important. In the cool region 20 inches may be sufficient, but 60 inches may be insufficient in a hot climate, particularly if strong, dry winds prevail. There, evaporation will account for much of the water loss and plants cannot obtain enough for growth.

Semiarid. Regions with more rainfall than arid ones but less than subhumid ones.

Subhumid. Regions with less precipitation than humid but more than semiarid areas.

Colloid. See Soil Colloids.

Composite Sample.

Soil. One made up from similar quantities of soil collected from a number of places in an area or field.

Fertilizer. A sample made up by taking samples from a number of bags or lots of fertilizer and mixing these subsamples.

Contour Farming. Producing crops by a system in which all tillage, seeding, and harvesting operations are carried out on the contour.

Contour Furrowing. The production of furrows on the contour in pastures or in the drier areas for catching and holding water. In some areas contour furrows are made for aiding in flood control.

Contour Line. A level line across a slope. All points in it are on the level.

Contour-strip Cropping. A system of cropping sloping land in contour strips. To be successful in controlling soil erosion, it is essential to alternate soil-protecting crops with soil-exposing ones.

Cover (for Soils). A soil on which the second growth of meadow, late growth of pasture, small-grain stubble, good meadow seeding, weed growth or well-distributed straw from the combine is said to have a good *cover* from the standpoint of protection against erosion by wind or water.

Cover Crop. A crop established for the purpose of protecting the soil, usually during winter and early spring, against blowing and washing. In some areas cover crops may be needed in summer and early fall.

Denitrification. Under conditions of lack of oxygen in the soil because of its being waterlogged or excessively compacted or crusted over, certain organisms break down nitrates in the soil to nitrites, ammonia, or even free nitrogen. This process is called denitrification.

Drift (Glacial). The unassorted material that consists of fine soil material, gravel, stones, and boulders. Used also in a wider sense to include many soil materials that originated in one place and that have been deposited in their present location. Moving sand is often spoken of as drifting sand.

Drumlin. A hill composed of glacial till or drift, usually unassorted. In shape it resembles somewhat that of a pear cut in two with the flat surface

of one-half of it on the earth. The blunt or higher end, however, is not relatively so blunt as that of the half pear.

Element. A simple substance that enters into the composition of soils and crops. Until recently the element was considered to be the smallest division of matter. Nitrogen, oxygen, copper, and silver occur in nature as elements. They occur also in compounds. In fact, most elements occur in nature only in the form of compounds.

Erosion. The day-to-day or current removal of soils and soil materials from the land where they had been placed by soil-forming processes. Both surface and subsoil materials are subject to erosion.

Gully. The channels produced on slopes by water concentrated in depressions. These channels are too deep to be crossed by ordinary farm implements and are not filled by the usual methods of tillage.

Rill. A miniature gully that is easily obliterated or filled by ordinary seedbed preparation and cultivation. If left untouched, rills grow into gullies.

Sheet or Surface. The more or less uniform removal of soil from the surface of slopes. Rills that are filled by cultivation have the same final effect as sheet erosion.

Wave. The removal of sand and soils or soil materials by wave action on shore lines of oceans and lakes. The wearing away of bedrock shore lines might be considered as geological erosion because it is relatively slow.

Wind. The removal of soil and soil material by wind action. Medium-textured soils in the drier areas, sandy soils, sands, and organic soils in humid areas are most subject to injury by wind action.

Fertility (Soil). A soil which, under favorable conditions with respect to light, heat, moisture, oxygen supply, and tilth, produces vigorous plants and high yields is said to be one of high fertility.

Fertilizer. A material applied to soils for the purpose of improving crop growth and increasing crop yields.

Carrier. See Carrier.

Complete. A fertilizer that contains all three fertilizer elements, *nitrogen*, *phosphorus*, and *potassium*.

Incomplete. A fertilizer that contains only two of the fertilizer elements. Usually it is nitrogen or potash that is omitted.

Material. A fertilizer material usually contains only one fertilizer element. Familiar examples are nitrate of soda, superphosphate, or muriate of potash.

Mixed. A mixed fertilizer is one that consists of two or more carriers of fertilizer elements. It may be a complete fertilizer or it may have only two of the fertilizer elements. Mixed fertilizers are usually easily applied by machinery. *Factory*-mixed fertilizers are compounded in relatively large,

mechanized factories. *Home*-mixed fertilizers often are hand-mixed or mixed by simple mixing devices on the farm.

Field Stripping. The laying out of strips across the principal slope which do not follow strictly contour lines.

First Bottom. The flood plain of streams; land that is overflowed by normal floods; the bottom nearest the stream. Contrast with second bottom or terrace.

Fixation. See Nitrogen Fixation.

Floats. A term once much used for finely ground rock phosphate that was prepared for application to the soil in its natural, untreated condition.

Flocculate. To bring individual soil particles, especially colloidal particles, clay, and silt together into groups called aggregates or granules.

Flood Plain. See First Bottom.

Food (Plant). The compounds produced within plants that nourish their cells. In Great Britain and often in America plant food is used with the same meaning as plant nutrient. See Nutrients.

Forest Soil. Soil developed under forest conditions.

Friable Soil. One easily crumbled between the fingers; one that is not plastic.

Glacial Material. Unassorted soil material, fine, medium, and coarse, silt and clay, gravel, boulders, all mixed together as deposited.

Glacier. A body of ice formed in an area of perpetual snow. It moves by gravity out from the center of accumulation over plains or through valleys until, on land, the ice thaws or, in the sea, the ice breaks off in the form of bergs. Glaciers tend, on plains, to wear down the high and fill the low places. In valleys they tend to overdeepen them in places. During thawing, moraines are built up that clog the valleys and rearrange the drainage.

Granulation. See Aggregation.

Granule. See Aggregate.

Gravel (Soil Separate). Particles larger than 2 millimeters in diameter.

Gravitational Water. Water that drains freely out of soil.

Green Manure (Crop). A crop produced mainly for mixing with the soil in its green or immature condition.

Gully. See Erosion.

Hardpan. A hardened, compacted or cemented layer or horizon, through which water and air move very slowly if at all.

Horizon (Soil). A layer or stratum of soil nearly parallel with the land surface. Such a layer has fairly well-defined properties that resulted from soil-forming processes.

Heaving. The lifting of plants (also posts and stones) by the action of frost in soils that have a source of water under them. The growth of crystals of ice under the plants lifts them progressively.

Heavy Soil. One that contains relatively high proportions of clay and therefore is not easily worked. It is heavy work for a team to pull a plow through it. Hence, clayey soils are termed "heavy" ones.

Humid Climate. See Climate.

Humus. Well-decayed, fairly stable organic matter in soils.

Hygroscopic Coefficient. The maximum quantity of hygroscopic water that a soil can absorb from saturated air.

Hygroscopic Moisture. Water that an oven-dry soil absorbs from a moist atmosphere. It is very tightly held by the soil.

Igneous Rock. Rock that was formed by the cooling of molten mineral matter.

Immature. *Plants.* Those that are green or have not yet matured. Suitable for mixing with soils as green manure.

Soils. Soils that are young or still in the process of development.

Inoculation (Legumes). The bringing of nodule-forming bacteria into contact with leguminous plants or seeds. Only inoculated legumes can gather nitrogen.

Intertilled Crops. Those that are cultivated as are corn, cotton, vegetables, and similar crops.

Kames (and Kettles). Rounded, irregular hillocks, with depressions or kettles that are usually dry. These consist of irregularly assorted gravel. In outwash material the stratification is nearly horizontal, but in kames the strata slope in many directions. Dry or excessively drained soils are formed from kame materials.

Lacustrine Soils. Formed from soil materials that were deposited in glacial-lake waters. Silt and clay dominate lacustrine soils.

Leaching. The dissolving of soluble materials in soils by water which moves them downward by gravity, sometimes beyond the reach of crop roots, at other times out of the soil into streams.

Legume. A group of plants on the roots of which the right legume organism produces nodules. In the nodules the organisms fix nitrogen which the crop plant in turn uses in its growth. One of the principal values of the leguminous plants results from their ability to fix nitrogen.

Light Soil. Soils of a sandy nature that require only relatively little power to draw a plow through them are said to be of "light" draft. Hence the term "light" soil has come into common use. Contrast with "heavy" soil.

Lime. The term commonly used on the farm and in the industry to include all materials used for correcting or controlling soil acidity.

Burned. See Calcium Oxide.

Hydrated. See Calcium Hydroxide.

Limestone. See Calcium Carbonate.

Lister. A plow or furrowing implement that makes a furrow by throwing the soil to both sides. It was formerly used only in drier areas, but now is used also in humid areas.

Loam. A mixture of the different sizes of soil particles, none of which is in sufficient excess to give the soil its own properties.

Loess. Soil material consisting largely of coarse silt that was deposited by wind in its present location.

Marine Soil. Soil that has been formed from materials that were deposited in sea water but which have since been elevated well above sea level.

Marl. A deposit of calcium carbonate mixed with varying proportions of silt, clay, and organic matter. One or all of these may be present. Marl occurs in swamps, often under a layer of organic material—peat or muck. Some deposits that are relatively pure $CaCO_3$ are worked and used on soils instead of limestone.

Mature soil. An old soil in contrast with an immature one.

Mechanical Analysis. The process of separating a soil into the various sizes of particles.

Mineral Soil. One composed largely of mineral matter in contrast to organic soils.

Moisture Equivalent. The percentage of water held by soil against a force of approximately 1,000 times that of gravity.

Moisture (Soil). The moisture held by soils, some of which is of service to plants in their growth.

Mottled. An irregular distribution of colors, especially in the subsoil. Frequently, mottling of gray with yellow and brown iron stains, particularly, indicates poor drainage through the subsurface layer.

Muck. Well-decomposed black or dark-colored organic matter that accumulated under swamp conditions or in still water. It usually contains varying quantities of silt and clay. Many drained areas are devoted to vegetable or mint production.

Mulch. Covering of organic material used for reducing the temperature or evaporation. Straw, leaves, sawdust, shavings, and paper have been employed. Freshly stirred soil has been called a soil mulch, but this does little to reduce evaporation.

Neutral Soil. One that is neither acid nor alkaline in reaction, or that has a pH of 7.0.

Nitrification. The changing of nitrogen in organic matter to the nitrate (NO_3) form in which crop plants take much of their nitrogen.

Nitrogen Fixation. Symbiotic organisms live in the nodules on the roots of inoculated legumes. These organisms take nitrogen from the soil air and supply it to the host plant on which they live.

Nitrogen is combined with other elements by various commercial processes to form ammonia, nitrate of soda, nitrate of lime, urea, cyanamide, and other products. These processes also are called fixation of nitrogen.

Noncalcareous Soil. A noncalcareous soil contains no calcium carbonate. Contrast with calcareous soil.

Nonsymbiotic Bacteria. Organisms that live in the soil without connection with plants, but which fix nitrogen. Contrast with symbiotic organisms.

Nutrients (Plant). The elements absorbed by plants for use in their growth. Fourteen or more elements are required by plants.

Organic Matter (Soil). Material in soils that came originally from plants and animals. Most of it is in an advanced stage of decay. See Humus.

Organic Soils. See Muck and Peat.

Optimum Moisture. The moisture content of soil that produces the best growth.

Optimum Temperature. The temperature at which plants make their best growth.

Oxide. A compound of oxygen and any one other element, such as carbon dioxide, CO_2.

Parent Material. For soils, the material from which soils and subsoils developed.

Parent Rock. The rock from which parent soil materials were formed.

Peat. Undecayed or only partly decomposed organic matter that accumulated in lake or pond water. Compare with muck.

Percolate (verb). Water passing downward in soil is said to percolate into or through the soil.

Percolate (noun). The water that passes through the soil.

pH. A system of designating the degree of acidity or alkalinity of a substance. Neutrality is pH 7.0. Higher values indicate increasing alkalinity and lower values increasing acidity. See Fig. 103.

Phase (Soil Type). A variation from the normal or prevailing conditions in a soil type. There may be stony, gravelly, shallow, deep, dark- or light-colored deviations from the normal for a soil type. See Series (Soil).

Physical Analysis. See Mechanical Analysis.

Plant Nutrient. See Nutrients.

Plastic Soil. One that, with the right moisture content, may be molded or formed with ease. Contrast with friable soil.

Plow Sole. A compact zone at the bottom of the furrow. It may result from plowing year after year at about the same depth, particularly if the soil is slightly too moist at plowing time.

Prairie Soil. One formed under grass in contrast with soil formed

under trees. Contrast with timber soil. Prairie soils under similar moisture conditions usually contain more organic matter than do timber or forest soils of similar make-up.

Porosity. Porosity in soils is expressed as a percentage of the total volume of soil and included air that is occupied by air. Fairly high porosity is associated with good tilth.

Productivity (Soil). The relative ability of a soil to make good yields of crops under favorable conditions with good treatment. Some soils have high natural productivity; others low productivity.

Profile (Soil). A section through the layers or horizons from the surface down into the parent material.

Puddle. To destroy the granules or aggregates of heavy soils.

Reaction (Soil). The acidity or alkalinity of a soil stated in pH values.

Relief. The differences in elevation which usually indicate the natural drainage of the area.

Residual Soil. Soil that was formed from bedrock in its present location.

Rill. See Erosion, Rill.

Saline Soil. One that contains more than about 0.2 per cent of soluble salts but is not strongly alkaline. See Alkali and Alkaline Soils.

Salt. A base in reaction with an acid produces a salt. Water is an exception.

Sand. Soil particles between 0.05 and 1.0 millimeter in diameter. The largest particles are coarse sand, then medium, fine, and very fine sand, decreasing in size.

Second Bottom. A terrace level next above the flood plain or first bottom. Second-bottom land is above any ordinary flood.

Sedentary Soil. See Residual Soil.

Sedimentary Rock. Rock formed from rock-forming material that accumulated ages ago in still water. Limestones, sandstones, and shales are representative of sedimentary rocks.

Semiarid. See Climate.

Series (Soil). A group of soils of similar origin, parent materials, and mode of formation. Variations in the size distribution of particles in the topsoil produce different types within a series.

Sheet Erosion. See Erosion.

Silt. Soil particles between 0.05 and 0.002 millimeter in diameter.

Soil. The natural material on the surface of the earth that holds moisture, supplies nutrients, and supports plant life.

Soil Colloids. These are very fine clay or organic particles. Because the particles are so tiny they have a tremendous surface area in comparison with their weight. Their relatively great surface constitutes one of the reasons for the high importance of colloids in soils.

Soil Erosion. See Erosion.

Soil Map. A map that shows soil types and phases in an area.

Soil Organic Matter. See Organic Matter.

Soil Separate. A group of soil particles such as sand, silt, or clay, within specified size limits.

Soil Series. See Series.

Soil Structure. Soil structure designates the arrangement of the particles with different types of groupings. Crumb and granular structures are favorable for plant growth. Compare structure with texture.

Soil Survey. The making of a soil map. This involves careful, detailed examination of the soils of an area and showing them in their proper location.

Soil Texture. Soil texture indicates the relative proportions of the different sands, silt, and clay in a soil. Compare with soil structure.

Soil Type. See Series (Soil).

Specific Gravity (Soil). The ratio of the weight of actual soil particles to the weight of their exact volume of water.

Stratification (Soil). The arrangement in layers of soil material such as sand and gravel.

Strip Cropping. See Contour Strip Cropping.

Stripping (Field). See Field Stripping.

Structure. See Soil Structure.

Subhumid. See Climate.

Subsoil. The part of the true soil below ordinary plow depth.

Surface Soil. Ordinarily, the upper part of the soil of approximately plow depth.

Symbiotic Organisms. See Nitrogen Fixation.

Symbiotic Relationship. That by which symbiotic organisms benefit their leguminous host plant and, in turn, are themselves benefited.

Terrace (for erosion control).

Bench. A bench developed by moving soil to the lower edge until the cultivated part is nearly level. The outer edge is usually very steep, sometimes supported by a masonry wall.

Drainage. Consists of a broad channel and a broad-based embankment. The channels and embankments are constructed across sloping lands for the purpose of conducting water to safe outlets instead of letting it flow over and erode the slope. The slope in the channel is very slight because the channel along with the rest of the field is under cultivation. The first broad-base terrace in this country was built by Preistly H. Mangun in North Carolina in 1885. The embankment is built from both sides. This is known as the Mangum terrace. The embankment of the Nichols terrace, named from its designer, M. L. Nichols, is built entirely from the soil that is taken out of the channel.

Terrace (Physiography). Usually a gently sloping or undulating area adjacent to a first bottom or lake plain. Because of its mode of formation by erosion by the stream or waves, the front is rather steeply sloping. These terraces along streams represent former flood plains. Some of the older terraces have been so eroded that they present a hilly appearance.

Texture (Soil). See Soil Texture.

Till. A mixture of unassorted soil materials deposited by a glacier. See Glacial Material.

Till Plain. Usually an undulating soil area formed from glacial till.

Tilth (Soil). The condition of soils in relation to the growth of crops. Good tilth describes a condition that is favorable for the growth of crops and poor tilth an unfavorable one.

Timber Soil. See Forest Soil.

Tolerant. Capable of withstanding a condition usually unfavorable. Some plants are tolerant of soil acidity and others are tolerant of soil alkalinity.

Topsoil. The surface soil that is relatively well supplied with organic matter, in contrast with the subsoil that usually has less organic matter than the topsoil.

Transported Soil. Soil that has been moved from its place of formation, such as loessial soils or glacial soils.

Type. See Series (Soil).

Undulating Topography. Land that is gently sloping in different directions. Slopes are not steep enough to interfere with easy cultivation.

Virgin Soil. Soil that is in timber or native prairie sod. It has not been cropped in any way.

Volume Weight. The weight of unit volume (such as a cubic centimeter) of soil including its pore space. Numerically, the weight in grams of 1 cubic centimeter of soil.

Water Requirement. The units of water actually used by a plant to produce a unit of dry matter. It does not include evaporation from the soil.

Water Table. The upper surface of free water in the soil. The *temporary* water table is usually meant when referring to the water table.

Weathering of Rocks. The physical and chemical breakdown of rocks to soil material. Weathering of soil material and soil, however, continues.

White Alkali. Saline soil. See Saline Soil.

Wilting Point. The percentage of water in the soil at the time that plants wilt permanently and finally die.

Wind Strip Cropping. Strip cropping at right angles to the direction of the prevailing winds for the purpose of controlling the blowing of soils.

List of Visual Aids

The following list of visual aids may be used to supplement some of the material in this book. It is suggested that each film and filmstrip be previewed before use as some may contain information that is too advanced or too elementary.

These films and filmstrips can be obtained from the producer or distributor listed with each title. (The addresses of these producers and distributors are given at the end of this listing.) In many cases they can be obtained from your local film library or local film distributor; also, many universities have large film libraries from which they can be borrowed.

The running time (min), whether it is silent (si) or sound (sd), and whether it is a motion picture (MP) or filmstrip (FS) are listed with each title. All those not listed as color (C) are black and white. All of the motion pictures are 16mm; filmstrips are 35mm.

Each film and filmstrip has been listed only once, in connection with the chapter to which it is most applicable. However, many films and filmstrips may be used advantageously in connection with other chapters.

Chapter I—Getting Acquainted with the Soil

Know Your Land (USDA 10min sd C MP). Presents in a simple way the principles of land classification; identifies the eight classes of land; explains that each land class has its proper use and treatment.

Plant Speaks, Soil Tests Tell Us Why (Am Potash 10min sd C MP). Shows the taking of soil samples on the farm and the interpretation of soil tests.

Formation of the Soil (EBF 15min si MP). Introduces the soil cycle—the story of the disintegration of rocks including the work of the weather; stream erosion; and transportation by glaciers, wind, and waves; rain and air; and plants and animals.

Chapter II—Selecting Land for Farming and Country Living

The Farm and the Farm Woods (USDA FS). The farm woods are as much a crop-producing unit as any other part of the farm and with proper care and management yield high-quality products for sale and home use.

Farm Woods: A Safe Crop for Steep Lands: Upper Mississippi Valley (USDA FS). Shows which practices should be avoided to prevent erosion and which others should be used to check erosion on farm woodland.

Chapter III—Tilling and Managing Crop Soils

A Way to Plow (BIS 22min sd MP). Shows an economical way of plowing.

Just Weeds (NFBC 20min sd C MP). Presents a survey of the damage caused by weeds, their spread, identification, and control.

Chapter IV—Controlling Water in Soils

Wetlands (USDA 11min sd MP). Shows how some wet lands can best serve as they are; others can be used for farming by proper water control and drainage.

Harvesting Native Grass Seed (USDA 11min sd C MP). Describes methods of harvesting grass and cleaning seed; value of native grass for soil and water conservation.

The River (USDA 30min sd MP). A dramatic documentary of the Mississippi from pioneer days of commerce to recent floods and erosion disasters; need for conservation.

Flood! (USDA 11min sd MP). Portrays the recurring rural and urban damage caused by floods, including costly sedimentation of reservoirs and injury to farm lands and city properties; presents conservation measures that are being adopted on uplands to check floods at their source.

Reclamation in the Arid West (USDI 11min sd MP). Shows projects on Western deserts, Hoover and Grand Coulee dams; effect on farm family.

Snow Harvest (USDA 25min sd C MP). Shows how the Soil Conservation Service and the Forest Service measure the winter snowfall in the Western mountains so that the amount of water available for farmers the next summer can be accurately predicted.

Irrigation (EBF 15min si MP). Gives impression of the need for and the result of irrigation; sources of water used for irrigation and methods of conduction to fields where it is used.

Irrigation Farming (EBF 11min sd MP). Pictures irrigation canals and furrow and flooding methods.

The Story of the Forest (United 40min sd MP). Describes its vital role in water control and soil erosion; early lumber industry and later reforestation efforts.

Chapter V—Controlling Soil Erosion

Wise Land Use Pays (USDA 19min sd MP). Illustrates reclamation of gullied land, checking of erosion by diversion ditches, terracing, strip-cropping, use of grasses, clovers, and soybeans.

Terracing in the Northeast (USDA 11min sd MP). Shows construction and uses of terraces and other erosion-control measures as applied to the Northeastern part of the United States.

Planning to Prosper (Allis-Chalmers 22min sd C MP). An attractive presentation of proper soil management, stressing contour farming and terracing.

Save the Soil (USDA 11min sd MP). Discusses the problem of soil conservation; shows part the soil has played in history.

Wind Erosion: Its Control on the Southern Great Plains (USDA FS). Portrays erosion starting in a number of ways and leaving a varied and tragic trail; shows how to prevent and control it by practices that save rainfall and soil.

Soil and Life (Case 11min sd C MP). Describes formation of soil over millions of years; how erosion can ruin it in a very short time; emphasizes practical measures being employed by modern conservationists.

Rain on the Plains (USDA 11min sd MP). Illustrates the effects of wind erosion on land; reclamation steps; measures to conserve rainfall.

The Cycle of Erosion (Ideal 11min si MP). Depicts the principles of erosion; development of valleys through youth, maturity, and old age.

It Can Happen Here (Harry Ferguson 35min sd MP). Dramatizes the mutual dependence of both farmer and businessman on the sustained productivity of the land; explains modern methods of undertaking soil conservation work.

This Is Our Land (Ethyl 26min sd MP). Highlights the importance of soil conservation; shows effect of overcropping and water and wind erosion; numerous ways to remedy these conditions.

Masters of the Soil (Ethyl 25min sd MP). A dramatized presentation of a farm family who learned that we can be masters of the land by using it and saving it for the future rather than letting erosion of the soil determine our destiny.

A Heritage We Guard (USDA 30min sd MP). Describes the early exploitation of wild life and land for more crops; interrelation of wild life and soil conservation.

Soil Erosion and Its Control in Orchards (USDA FS). Shows how runoff and wind ruin orchards by gullying and drifting soil; control of such erosion by preventive practices and the use of brush mulch.

Under Western Skies (International Harvester 30min sd C MP). Presents the story of natural resources in the Far West and the conservation measures being taken to protect them; emphasizes soil and water conservation.

Soil Erosion (MOT 6min sd MP). Gives a vivid impression of the results of soil erosion; illustrates control techniques.

Building Back (Allis-Chalmers 25min sd C MP). Shows how erosion is robbing us of our wealth; explains how we can prevent this destruction by soil conservation, contour farming, and growing cover crops.

Build Good Terraces (Case 12min sd MP). Describes how to build a modern channel-type terrace with a two-bottom moldboard plow.

Broad Base Terracing (Case 12min sd C MP). Shows how to build a terrace with a one-way disk plow.

Work of the Atmosphere (EBF 11min sd MP). Shows how the atmosphere plays a part in altering the earth's surface through erosive action of the wind and sandblast action on rocks and trees; how it works with surface water.

Food and Soil (USDA 11min sd C MP). Highlights of soil conservation in the United States.

Permanent Agriculture (International Harvester 30min sd MP). Presents the latest methods of soil conservation.

New Ways in Farming (MOT 15min sd MP). Shows the effect of depression, dust storms, floods, and erosion on farm lands; illustrates how the average farm, properly managed, can be a source of good living, health, and independence.

Soil Conservation Benefits Wildlife (USDA FS). Shows how nature reclaims areas saved by soil conservation and so provides cover for game and other wildlife and habitats for fish.

Corn-Belt Farmers Fight Erosion (USDA FS). Illustrates how the Corn-Belt farmers may fight erosion by contour farming, terracing, rotation, diversion drainage, check dams.

First Things First (USDA FS). Shows how grassing of waterways controls erosion; contouring holds runoff on land of gentle slope; grassed waterways direct it on steeper slopes.

Establishment and Maintenance of Grassed Waterways (USDA FS). Shows how gullies cause damage; how to slope and seed them to serve as waterways.

Home on the Range (USDA 11min sd MP). Describes government plans for control of erosion in the public domain; activities in control of erosion, such as flood control, protection of grass, construction of driveways, and the seeding of overgrazed areas.

For Years to Come (USDA 20min sd C MP). Illustrates the change-over from old straight-row method to modern conservation farming methods; contour plowing.

Tree Planting and Land Use (USDA FS). Shows how mistakes in land use result in loss of yields and soil; ruined land may be made useful with plantings adapted to sites and proper care as they develop.

In Common Cause (USDA 20min sd MP). Shows what soil conservation districts have accomplished; how they are formed and operated; and the big job yet to be done in this vital program for increasing crop production and saving our soil.

Contoured Acres Fight (USDA FS). Farm on the level and save water, fertilizer, and soil; contoured acres will grow more crops.

Chapter VIII—Keeping up Organic Matter and Nitrogen in Soils

Fungi Snare and Destroy Nematodes (USDA 11min sd MP). Pictures how certain fungi devour nematodes and how organic matter is broken down to enrich soil.

Deficiencies in Plant Growth: A Study of Mineral Elements (Rutgers 30min sd MP). Describes the effects of elements in growth of tobacco, cotton, peas, buckwheat, and tomatoes.

Life of the Soil (National Fertilizer 33min sd C MP). Emphasizes the necessity for growing legume and nonlegume cover crops; how man has adapted nature's methods to improve soil.

Chapter XI—Selecting and Using Commercial Fertilizers

Living Rock (Georgia 30min sd C MP). Illustrates how a poor farm is built up into a good farm producing bumper crops by use of lime and phosphate.

Putting Plant Food to Work (National Fertilizer 20min sd C MP). Development of fertilizer application; problems encountered; movement of fertilizer in soil; results obtained from correct methods.

Growing Plants without Soil (Unit 11min si MP). Presents a new scientific method of agriculture whereby "soilless acre" produces vegetables; chemical diet for each type of plant.

Chapter XII—Planning Systems of Crop Rotation

The South Grows Green (USDA 25min sd C MP). Shows how crop diversification is replacing the old, destructive one-crop system, and the resulting production.

Cotton Growing (EBF 11min sd MP). Depicts planting and cultivating cotton, the boll weevil, picking cotton, preparing cotton for market, cotton-growing belt.

King Cotton (DuPont 11min sd MP). How to become a successful cotton grower; prevention of loss from disease.

King Cotton (GM 22min sd MP). Describes cotton development from Eli Whitney to modern cotton gin; modern farming, operating of gin; uses of cotton.

Sam Farmer's Cotton (United 30min sd MP). Portrays good practices in cotton production, seed selection, soil requirements, cultivation, fertilization, picking.

Seeds of Prosperity (DuPont 11min sd MP). Tells how farmers and scientists are conquering the boll weevil and other scourges.

Wheat (A & B 11min sd MP). Evolution of the wheat industry; pioneer farming, wheat farming with machinery, storing and marketing.

The Corn Farmer (EBF 11min sd MP). Problems of crop rotation, planting, cultivating, harvesting, haying, hog and cattle raising, marketing, role of machines.

Save That Soil (Am Potash 28min sd C MP). Depicts the early South, results of one-crop system, reclamation, conservation of Southern soils through use of legumes and modern methods of soil management.

Crown of the Year (BIS 22min sd MP). Harvesting of grain and root crops; farmer plans best disposition of acres for coming year.

Grass and Clover Seed Production (BIS 22min sd MP). Best methods of sowing, fertilizing, cutting, and threshing.

Make Fruitful the Land (BIS 22min sd C MP). Traces history and present-day use of rotation-of-crops theory and mixed farming.

Chapter XIII—Managing Pasture Soils

Muddy Waters (USDA 11min sd MP). The story of land use and abuse in the Southwest; shows how grazing and farming depleted soil-binding vegetation.

Green Acres (National Fertilizer 20min si C MP). Emphasizes pasture improvement; grazing of various livestock and typical pastures.

Reseeding for Better Grass (CFC 11min sd MP). How to turn coarse pasture lands into good grazing lands by reseeding.

Level Farming on Sloping Fields (Case 10min sd MP). Shows the application of modern power farm equipment to the latest recommended soil-conservation practices with reference to contour farming, contour-strip farming, and pasture improvement.

Grasslands (USDA 10min sd MP). Discusses the problem of soil conservation on the grazing lands of the arid Southwest; sheep and cattle on the open range and approved methods of attack on the evils of overgrazing.

Chapter XIV—Managing Garden, Fruit, and Lawn Soils

Gardening (EBF 11min sd MP). A carefully planned garden-raising project; aspects of soils; role of sun; pests; parts of plants used for food.

The Farm Garden (USDA 22min sd C MP). Fundamentals of garden husbandry, cultivating, control of pests and diseases.

Chapter XV—Keeping Soils Productive over the Years

Harvests for Tomorrow (USDA 27min sd MP). Discloses the basic need for soil conservation and sound pasture improvement; shows the use of soil-building practices in the Northeastern states.

SOURCE OF FILMS LISTED ABOVE

A & B—Akin & Bagshaw, Inc., 2023 E. Colfax Ave., Denver, Colo.
Allis-Chalmers Mfg. Co., Advertising & Public Relations Dept., Milwaukee 1, Wis.
American Potash Institute, 1155—16th St., N.W., Washington 6, D.C.
BIS—British Information Service, 30 Rockefeller Plaza, New York 20
Case, J. I., Co., Racine, Wis.
CFC—College Film Center, 84 E. Randolph St., Chicago 1
DuPont—E. I. DuPont de Nemours & Co., Tenth & Market Sts., Wilmington, Del.
EBF—Encyclopaedia Britannica Films, Inc., 20 N. Wacker Dr., Chicago 6
Ethyl Corp., 405 Lexington Ave., New York 17
Harry Ferguson, Inc., 15020 Woodward Ave., Detroit, Mich.
GM—General Motors Corp., Broadway at 57th St., New York 19
Ideal Pictures Corp., 28 E. Eighth St., Chicago 5
International Harvester Co., 180 N. Michigan Ave., Chicago 1
MOT—March of Time, 369 Lexington Ave., New York 17
National Fertilizer Assn., 616 Investment Bldg., Washington, D.C.
NFBC—National Film Board of Canada, 84 E. Randolph St., Chicago 1
Rutgers Films, Dept. of Biophotography, Rutgers University, Box #78, New Brunswick, N.J.
USDA—U.S. Dept. of Agriculture, Motion Picture Div., Washington 25, D.C.
USDI—U.S. Dept. of the Interior, Motion Picture Div., Washington, D.C.
United World Films, Inc., Rockefeller Center, New York 20

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